DISTRIBUTION AND ABUNDANCE OF THE PACIFIC RAZOR CLAM,

Siliqua patula (Dixon),

ON THE EASTSIDE COOK INLET BEACHES, ALASKA

by

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A

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By

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ABSTRACT

Three questions were asked about the population of the Pacific razor clam Siliqua patula (Dixon) on eastside Cook Inlet beaches: (1) can density be estimated by a three-stage stratified random sampling plan; (2) can age composition data be used for age-structured population estimation; (3) does substrate composition affect clam density? Field studies of Coho, Ninilchik and Clam Gulch beaches obtained precise density estimates for Clam Gulch beach only (coefficient of variation = 14.6%, 1988, and cv = 13.6%, 1989). A heavily exploited area of high density at Clam Gulch was resampled extensively in 1989 to determine if a significant harvest rate was detectable. No significant harvest rate was detected. A catch-at-age model was successfully applied to age-structured data, and estimates of abundance for ages 4 through 11+ in years 1977 to 1989 were generated. There is some evidence from substrate analyses that clams are found in higher abundance where grain sizes 0.125 to 0.400 mm predominate.

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INTRODUCTION

The largest sport fishery for the razor clam, *Siliqua patula* (Dixon), in Alaska occurs on the eastside beaches of Cook Inlet, between Kasilof and Anchor rivers (Figure 1). This razor clam population provides an increasingly important recreational opportunity as well as an economic stimulus to the Kenai Peninsula. A general increase in the annual harvest of razor clams from 279,480 individuals in 1977 to over a million since 1984 has accompanied a 2-fold increase in effort over the same period, according to statistics reported by the Alaska Department of Fish and Game (ADF&G) (Mills 1977...1989).

ADF&G began to monitor the Eastside razor clam populations in 1965 following the Good Friday earthquake of 1964, which caused subsidence of beaches in the Cook Inlet area (Nelson 1982, Nickerson 1975). Increased exploitation by sport diggers also occurred due to improvements made to access roads in the late 1950's. Catch-per-unit-of-effort (CPUE), defined as the average number of clams dug by one harvester per clam tide, has been used by ADF&G as an index to relate harvest to stock abundance. CPUE increased from 1969 until 1975 from 29.5 clams per unit of effort, to 38.1, decreased steadily to 26.6 in 1980 and climbed to 38.3 in 1987, the highest recorded CPUE (David C. Nelson, Alaska Department of Fish and Game, Sport Division, Soldotna, AK, pers. comm.) (Figure 2). In 1987, at the inception of this study, high CPUE, the large size of individual clams in the harvest [small individual size being an indicator of over-harvest (Weymouth et al. 1925)], and visual observations of new concentrations of clam stocks on southern beaches where few clams were found in the past, indicated that clams were not being over-exploited on the Eastside beaches.

In the face of large, increasing harvests and changes in use patterns, the need to predict population levels and to determine sustainable harvests was becoming more critical. Digger effort had

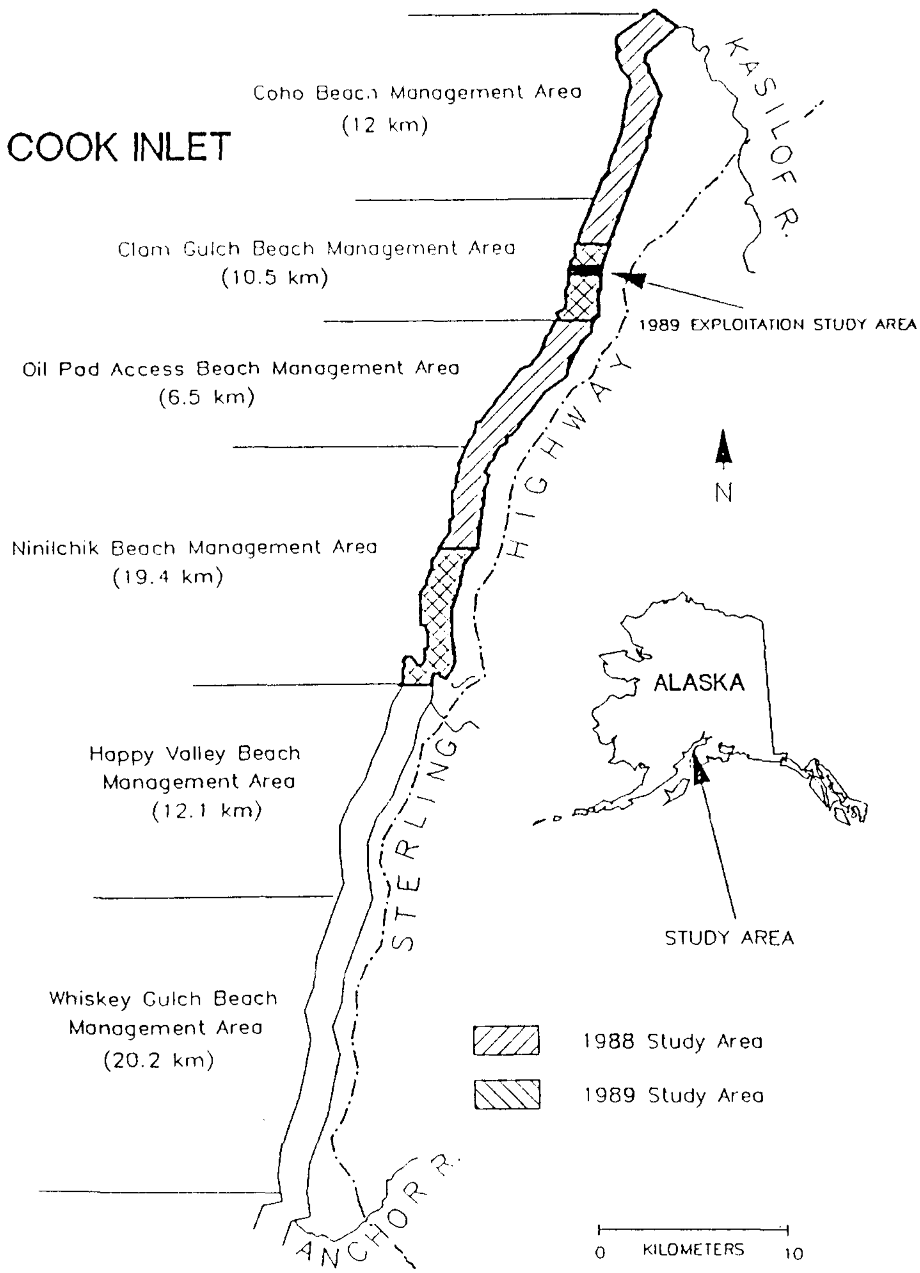


Figure 1. Eastside beaches, Cook Inlet, Alaska.

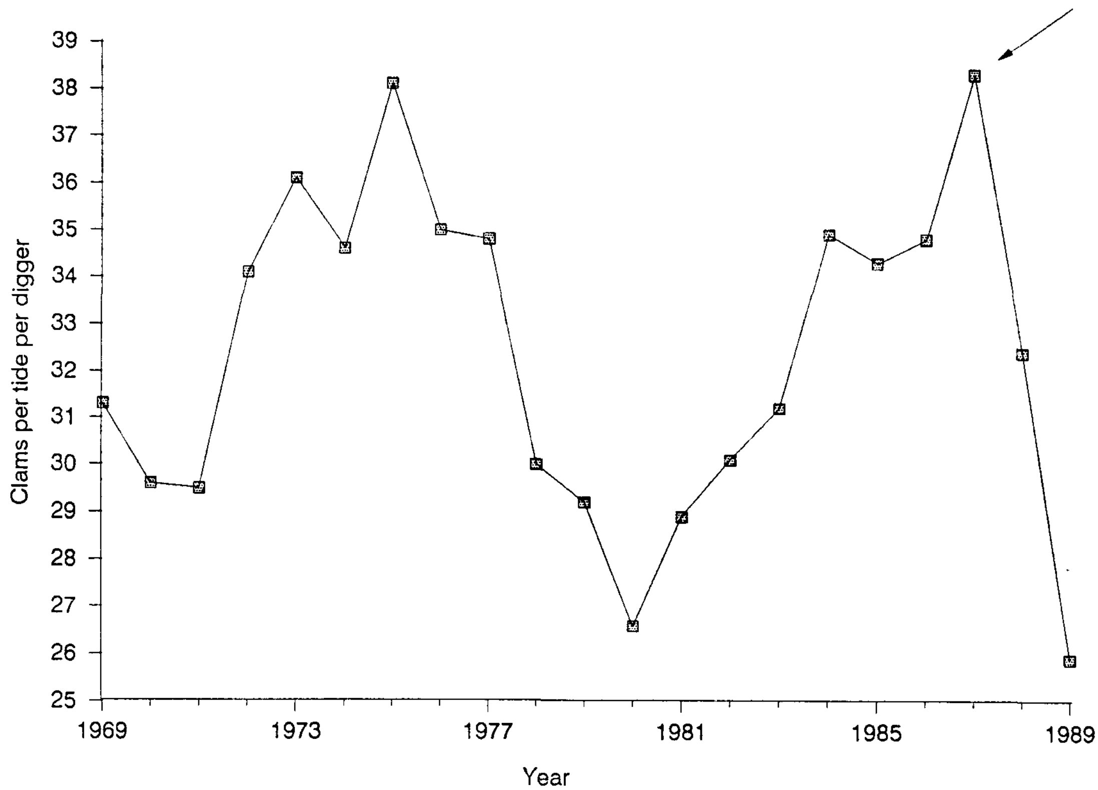


Figure 2. Catch-per-unit-of-effort at Clam Gulch from creel surveys 1969-1989.

shifted from Clam Gulch beach, a population well documented in department studies, south to Ninilchik beach, an area less heavily sampled. ADF&G biologists were concerned that trends in use patterns combined with adverse environmental conditions could trigger declines in the population and that the indicators of abundance might not reflect the true population size. Also, a major oil spill occurred in Cook Inlet in summer, 1987, signaling another factor which might affect the razor clam population in the future. (Oil from another major oil spill that occurred in spring, 1989, in Prince William Sound was found in small amounts on Eastside beaches.) A cooperative study between ADF&G and Juneau Center for Fisheries and Ocean Science (JCFOS) of the University of Alaska Fairbanks was developed to extend department studies by further analysis of existing data, to determine actual population numbers and the influence of environmental variables on razor clam population size and distribution on the eastside Cook Inlet beaches. This thesis reports on the findings of that study.

Chapter 1 describes the life history of the Pacific razor clam to provide an understanding of the factors influencing the population dynamics of the species. The second chapter explains the sampling procedures and statistical analyses used to determine the density estimates for the various beaches considered in the study. Population parameters from age-structured analyses of length-age relationships are presented in Chapter 3. Chapter 4 contains the results from the study of environmental factors thought to influence razor clam distribution. Recommendations for future management are presented in the fifth chapter.

Razor clam dip

1 c canned razor clams
1 8 oz pkg. cream cheese
1-2 T mayonnaise
1 t fresh chives

Soften the cream cheese. Dice the clams and add them to the cream cheese. Mix in the mayonnaise and chives. Mix in clam juice to the desired consistency. Sprinkle the top with paprika. Chill for one hour or more.

CHAPTER 1

LIFE HISTORY OF THE PACIFIC RAZOR CLAM

Weymouth et al. (1925) and Weymouth and McMillin (1931) conducted the first research on razor clams in Alaska. These research efforts were primarily concerned with age and growth of razor clams as they related to commercial fisheries. In 1975, Nickerson presented the results of extensive studies of the life history of razor clams in the Cordova area. Nelson (1982) documented the research efforts being conducted by ADF&G on razor clams from the eastside Cook Inlet beaches and related the life history of razor clams from the eastside Cook Inlet beaches to previous studies conducted in Alaska and British Columbia, Washington and Oregon. The following description is drawn from these and other references to the life history of the Pacific razor clam as well as observations made by this author.

Habitat and distribution

The razor clam, is a resident of exposed fine and medium grain sandy beaches along the west coast of North America from Pismo Beach, California to the Bering Sea (Weymouth and McMillin 1931). Eight major areas of clam abundance occur: one in Oregon, one in Washington, two in British Columbia and four in Alaska (Bourne and Quayle 1970). Large populations are found on Alaskan beaches at Swickshak, Cordova, Polly Creek and the east side of Cook Inlet.

The population on the eastside beaches of Cook Inlet is found in typical razor clam habitat. The beaches are comprised of stretches of sand, silt and gravel. The substrate on the beaches south of the Oil Pad Access Management Area (Figure 1) is coarser and the beach slope is steeper than that found on the northern beaches. The beaches are often exposed to heavy wave action and precipitation.

Clams have been recovered from 54.9 m below the mean lower low water mark (Nickerson 1975) but the majority of razor clams are found between the low tide mark to 30-60 m beyond the low tide surf line (Bourne 1969). Nickerson (1975) found razor clams were infrequent at the +1.2 m tide level but increased in abundance to a high point at the zero tide level and then decreased at lower tide levels sampled. I found a clam at the +1.7 m tide level and a group of clams at the -1.6 m level during sampling in 1989.

The relationship between frequency of occurrence, age and length of razor clams and tide level is disputed. Large numbers of small clams have been observed in the subtidal. McMillin (1924) collected many juvenile clams at depths of 3.3 m below mean low water off the Washington coast. Observations of large numbers of juveniles but few adults were reported in studies by the Washington Department of Fisheries (WDF) from 1983 to 1985 (Lassuy and Simons 1989). Densities of 38,000 juvenile clams per m^2 were estimated in the Washington subtidal in 1986 (Rickard et al. 1986). Densely populated beds of adult clams were observed by divers at depths of 5.8 m adjacent to the Oregon coast (Lassuy and Simons 1989). Nickerson (1975) found more older larger clams than juvenile clams at lower tide levels. I found concentrations of juvenile clams in the same areas as adults but juveniles were concentrated in the clam beds farthest from shore (see Chapter 2).

<u>Spawning and fecundity</u>

The life cycle of the razor clam is characteristic of most marine bivalves. The sexes are separate; a female broadcasts 6-10 million eggs into the currents where they are randomly fertilized by sperm from males (Kaiser 1977). Egg production in the Cordova area ranges from 300,000 eggs for a 40 mm clam up to 118.5 million for a 180 mm clam (Nickerson 1975). The average female razor clam (120 mm to 130 mm) contains between 24 to 30 million eggs (Nickerson 1975). Little is known about the fecundity of clams on the Eastside beaches.

Eggs and sperm of the razor clam are released over a period of variable length from May to October. Temperature is the primary factor triggering spawning in razor clams (Nickerson 1975, Nelson 1982). Weymouth et al. (1925) and Fraser (1930) thought spawning was triggered by temperatures around 13° C. Bourne and Quayle (1970) observed spawning at temperatures below 13° C on Massett and Long beaches in British Columbia. Nickerson (1975) indicated spawning occurs with the accumulation of 1,200 to 1,500 temperature units. Seawater temperature of about 8.3° C appears to serve as the threshold temperature on Alaskan beaches (Nelson 1982).

Spawning is also influenced by upwelling, tidal cycles, currents, food availability and gonad maturity (Bourne 1969, Nickerson 1975, Weymouth et al. 1925). Breese and Robinson (1981) successfully induced spawning in the laboratory by increasing the concentration of a food source, the dinoflagellate *Pseudoisochrysis paradoxa*.

The exact time of spawning each year is highly variable and changes with geographic location (Weymouth et al. 1925, Weymouth and McMillin 1931, Nickerson 1975, Tegelberg 1961, Bourne and Quayle 1970, Nelson 1982). Spawning of razor clams in Alaska occurs between June and September (Nickerson 1975, Nelson 1982); Nickerson (1975) reported razor clams in the Cordova area spawned in June or July. Spawning of clams on eastside Cook Inlet beaches has been observed most frequently from the end of August to late September, earlier on the southern beaches of Ninilchik, Happy Valley and Deep Creek (Nelson 1982). I observed spawned clams as early as mid-July in 1989 at Clam Gulch.

Survival

Spawning of razor clams in Alaska appears to be an annual event (Nelson 1982). However, the setting (settling of clams to the substrate towards the end of the larval period) of clams is not. Survival is quite low for razor clams from fertilized ova to larval setting (Nelson 1982). Bourne (1969) suggests it is of the order of 1 in 100,000. The primary factors governing juvenile survival appear to be physical, not biological (Hancock 1970, Nelson 1982).

The larval period of razor clams is 8 to 10 weeks, longer than that of most mollusks (Weymouth et al. 1925). After the gametes are released, the fertilized egg (zygote) develops into a swimming trochophore larva which becomes a veliger. During the veliger stage many adult characteristics are formed; at its terminus the young clam settles to the substrate. Disagreement exists about many aspects of the larval period. Weymouth et al. (1925) indicated the free swimming stage is 8 weeks, while Nickerson (1975) and Nelson (1982) claimed it is 5 to 6 weeks. The extent and agents of larval dispersion are uncertain. McMillin (1924) suggested that nearshore currents can redistribute larvae "several miles" at least. Weymouth et al. (1925) suggested that larvae settle rapidly because their swimming stage is limited.

Juvenile razor clams live in the top few centimeters of substrate and are exposed to heavy wave action, temperature fluctuations, salinity changes and other environmental perturbations to a much greater extent than adults. Young clams may also suffer in competition for food when deposited in beds heavily populated by adults (Nelson 1982). Razor clams are filter feeders, feeding mostly on phytoplankton, largely diatoms (Weymouth et al. 1925). In many clam species, adults have more energy reserves and are therefore better competitors when food is scarce (Hancock 1970). Other factors affecting juvenile survival besides lack of available food are: predation by gulls, ducks, and a few fish species, and hyposmotic stress (Bourne 1969, Tegelberg 1964, McMillin 1929, Feder and Paul 1974, Hancock 1970). Years may pass when cohorts are nonexistent in samples due to extensive mortality of larval or juvenile clams. At Long Beach, British Columbia, Bourne and Quayle (1970) observed dead young-of-the-year razor clams in windrows 1.8 to 3.7 m wide, 15 to 30 cm deep and 12 to 15 m long and a decline of live young in samples, from August to November of 1961. This year-class was poorly represented in samples taken in subsequent seasons. Nelson (1982) found only three strong or predominant year-classes over a 16 year period on eastside Cook Inlet beaches although there was evidence of yearly spawning by adults. No young-of-the-year and few juvenile clams had been found on Eastside beaches until the inception of this study.

Mortality rate decreases as adult size is reached. The natural mortality of adult Alaska razor clams is comparatively low (Nickerson 1975). Estimated survival from three years of age and upward is 0.4029 per year in the Cordova area (Nickerson 1975). McMillin (1924) estimated mortality rates of 10% for adult clams. Survival rates from this study are presented in Chapter 4.

Age and growth

Growth rates, age at which largest increase in size occurs and maximum size vary with latitude (Weymouth et al. 1925, Weymouth and McMillin 1931, Tegelberg and Magoon 1969, Bourne and Quayle 1970). Generally, growth rates are slower on the northern end of the range but those clams reach a larger total length than more southerly populations and have a longer life span (Weymouth and McMillin 1931, Nelson 1982). Razor clams attain a maximum age of 5 years at Pismo beach, California and 9-11 years on Oregon and Washington beaches. The oldest razor clams observed in Alaska achieved an age of 18 years (Nickerson 1975). However, the largest razor clams found are generally not the oldest (Nickerson 1975). Growth rates on the beaches of Oregon and Washington are approximately twice those found in Alaska (Nickerson 1975). Weymouth et al. (1925) found that clams on southern beaches grew to 2/3 of their maximum size in the first year following settling while in northern latitudes four years were required for the same amount of growth.

Sexual maturity of razor clams depends more on size than age. A razor clam is considered to be fully recruited into the spawning population when it reaches a size of 100 mm. Razor clams in Alaska reach sexual maturity and are fully-recruited (>100 mm) between their fourth and sixth growing seasons (Nickerson 1975, Nelson 1982). Almost 100% of the razor clams sampled from the Cordova area had reached sexual maturity by their sixth growing season Nickerson (1975). Nelson (1982) reported Eastside Cook Inlet razor clams reach 100 mm by the formation of their fifth annulus (4.5 years).

Nelson (1982) provided the information that is available on growth rates of eastside Cook Inlet razor clam stocks. Peak growth occurs in the first season following setting and gradually declines; most is attained by age 5.5. Growth is more rapid and larger-sized clams are found from Ninilchik south.

No major differences between the life history of male and female razor clams have been reported (Weymouth et al. 1925, Weymouth and McMillin 1931, Nickerson 1975, Nelson 1982). Weymouth et al. (1925) concluded no differences exist in male and female razor clams on the basis of maturity and growth. Nickerson (1975) found the sex ratio of razor clams in the Cordova area to be 1:1. He also indicated no differences in growth between the sexes. Weymouth and McMillin (1931) indicated females have slightly faster initial growth. However, after three or four years, males reach a larger size and appear to outlive the females by one year.

Movement

Young razor clams (10 mm in valve length) are capable of voluntary movement of about 60 cm along the exposed beach surface (Nickerson 1975, Bourne and Quayle 1970). Nelson (1982) felt further distribution is insignificant after settling occurs, however, new research indicates juveniles may migrate inshore from the subtidal (Daniel Ayers, WDF, Montesano, Washington, pers. comm.). Beyond the vulnerable size, razor clams exhibit little lateral movement except at Swickshak beach on the Alaskan peninsula where lateral movement was observed into the third growing season. Any lateral movement is the result of substrate instability (Nickerson 1975). Large razor clams move rapidly in the vertical plane (Nickerson 1975) and digging rates of 22 to 24 cm per minute have been measured (McMillin 1924 and Schink et al. 1983).

Razor clam linguini

(Serves 4)

2 c fresh or frozen razor clams, sliced
2 c sliced mushrooms
1 c chopped celery or broccoli
1 medium onion, sliced
1 T parsley
2 large garlic cloves, grated or pressed
2 T flour
white wine or cooking sherry
oil

Fry the garlic and parsley in the oil of your choice over low heat. Cook them until they are soaked with oil. Turn up the heat and add the razor clams, stirring rapidly. Cook the clams 1 minute and remove them. Add the onions and vegetables to the skillet and cook them until they are halfway to the desired texture. Add the mushrooms. Continue cooking until the mushrooms are soft. Remove the vegetable mixture and slowly sift the flour into the juice, stirring continually until it is a thick sauce. Thin it with wine to taste. Stir the rest of the cooked ingredients into the sauce. Turn off the heat. Salt to taste. Serve with parmesan cheese over noodles or brown rice.

CHAPTER 2

FIELD SAMPLING TO DETERMINE POPULATION PARAMETERS

The main objective of this study is to test the null hypothesis that the density of the razor clam population on the eastside beaches of Cook Inlet cannot be estimated. If the null hypothesis is rejected, then total abundance would be determined from the estimates of density obtained.

In Alaska, estimation of razor clam population size has been attempted only at beaches near Cordova. Nickerson (1975) employed five methods to estimate the abundance of razor clam populations: (1) density indicators and probability distribution on the low tide terrace for estimating the abundance of clams 90 mm and larger; (2) stratified random sampling to estimate clams 35 mm and smaller; (3) application of a probability density function to estimate population size where sampling is inadequate which may replace (2) with adequate sampling; (4) combining estimates based on dug and screened clams to estimate abundance of clams less than 90 mm and (5) mark-recapture estimates. The Washington Department of Fisheries manages a razor clam fishery in which over 3.0 million razor clams are harvested each year with mark-recapture methods and stratified random digs (Douglas Simons, WDF, Coastal Laboratory, Montesano, WA).

A sampling plan of the magnitude of the mark-recapture study implemented by WDF was impractical for the Eastside beaches because of personnel limitations. The first field season was in 1988. Equipment on hand lent itself readily to estimation of clam density. A systematic/stratified random survey at selected areas along the lines of Scherba and Gallucci (1976), Nickerson (1975), and Nelson (1982) was chosen. Primary strata were areas with high, medium and low clam densities, determined by a beach survey of clam shows and interviews with department personnel. These were chosen from among the traditional management areas (Figure 1). For each stratum, a three-stage sampling plan was carried out. The first-stage units (secondary strata) were transects within the primary strata. The second-stage units (tertiary strata) were beach levels chosen systematically each 15 meters (50 feet), with a random starting point from the gravel edge of the beach. Third-stage units were multiple samples taken at each beach level. Each sampling unit was a circular area of 0.5 m^2, chosen to satisfy logistic and sampling concerns. Clams were counted and a systematic subsample of 300 clams was taken for age determination.

In 1989, primary strata were redesignated to obtain less variable density estimates based on the results of sampling in 1988. Also a heavily exploited section of beach at Clam Gulch was sampled repeatedly in an attempt to detect changes in density that might be attributed to exploitation.

Sampling logistics

May and June of 1988 were spent surveying the beach to determine primary strata. To map clam distribution, personnel walked transects on the exposed beach during low tide series noting the abundance of clam shows. Patterns of abundance were used to determine primary strata. For samples collected during 1988, Stratum 1 (referred to subsequently as Coho) was determined to have sparse distributions of clams and extended 3.2 km south of the Coho beach access road to 1.8 km north of the Clam Gulch access road (Figure 3). Stratum 2 (Clam Gulch) had heavy concentrations of clams and extended from the southern boundary of the Coho stratum south of the Set Net access road 1.4 km. Stratum 3 (Ninilchik) was observed to have medium but quite variable clam densities and extended from the southern edge of the Clam Gulch stratum to Deep Creek.

During the 1989 field season the boundaries of the primary strata were modified based on analysis of the 1988 results. The Coho stratum was eliminated. The Clam Gulch stratum was limited to an area within 3.2 km

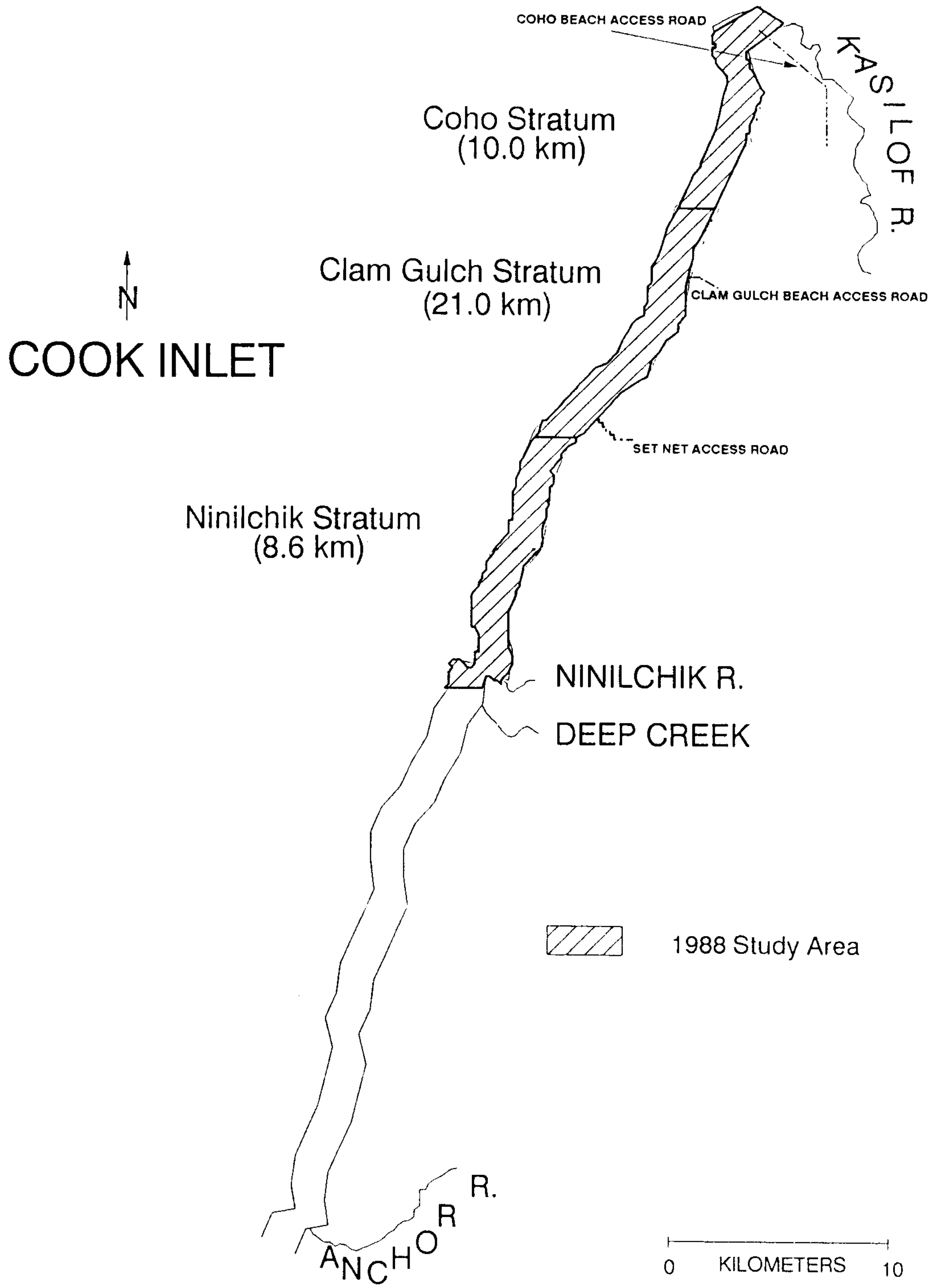


Figure 3. Primary strata: Coho, Clam Gulch and Ninilchik, sampled in 1988.

north of the access road and 4 km south of the road (Figure 4). The Ninilchik stratum was changed to include only the area between Leman's point and Deep Creek. A section of beach 0.8 km north of the Clam Gulch access extending 114 m north and 61 m south was designated the exploitation study area to be sampled extensively to determine if a significant harvest rate could be detected. The section was located in the center of Clam Gulch where exploitation occurs regularly.

Equipment during the first field season included two 2-cycle 1.5 horsepower Homelite pumps whose outlet and intake were modified with fittings to accept 15 m of collapsible cotton firehose and 6 m of stiff hosing, respectively. Difficulties with these two pumps required their replacement with a 4 cycle Honda pump in August of that year. The Honda pump was replaced with a new pump of the same make midseason in 1989. The 15 m outlet hose was also replaced with a 30 m hose to increase sampling time at each beach level. At the far end of the outlet hose a metal tube or "wand" was attached to direct the flow of water into the substrate (Figure 5). A pliable aluminum sheet metal strip, 25 cm wide with 1 mm diameter perforations, was formed into a sampling ring with a diameter of 0.79 m. The ends of the ring were held together with pop-rivets and a garden hose, cut on one side to fit on the edge of the ring and held in place with electrical wiring clamps, protected workers from cuts when the ring was pressed into the sand. The rigidity of the ring allowed a fixed area to be sampled and the perforations to decrease its weight and let water but not clams flow out of the sampling frame.

With a few modifications for adverse weather conditions, the following process was followed throughout the entire study with some modification to the site selection procedure during 1989. In 1988, on each day of the low tide series (a 0 meter or lower tide as indicated by the tide book), a site was chosen randomly using a four digit random number-the first indicated the primary stratum and the subsequent three, the location of the transect in miles, to the nearest tenth, from the

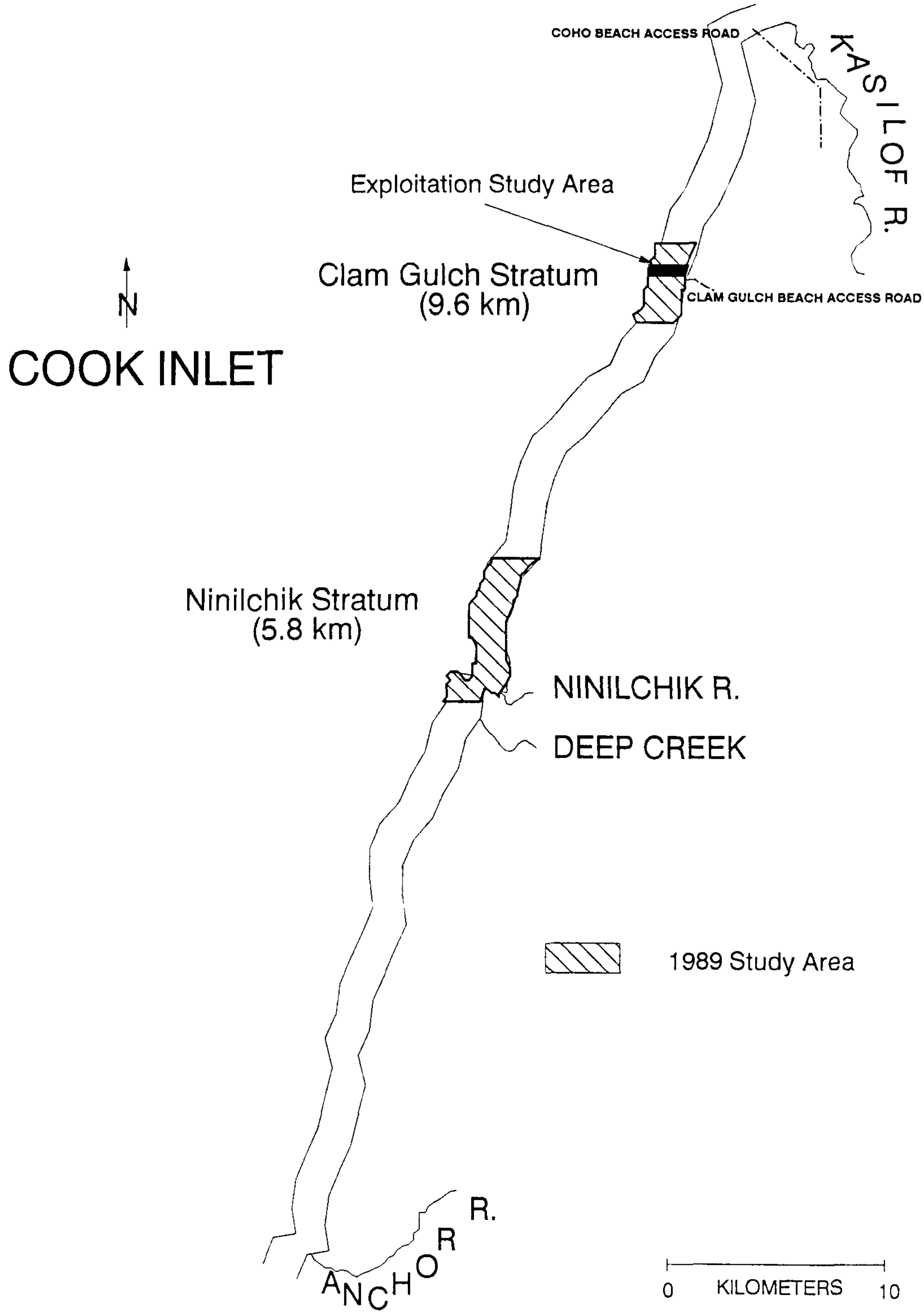


Figure 4. Primary strata: Clam Gulch and Ninilchik, and the exploitation study area, sampled in 1989.

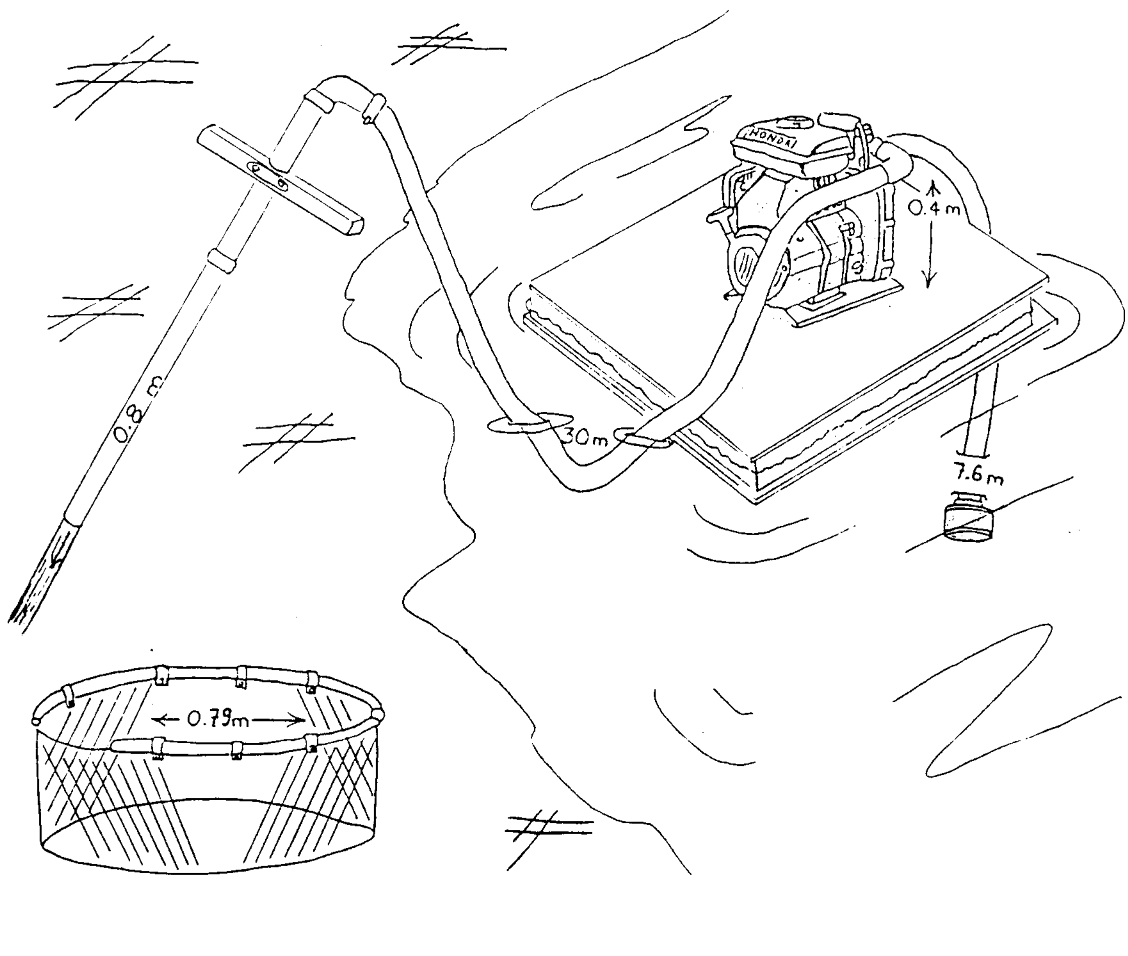


Figure 5. Sampling ring and pumping apparatus used in field sampling.

northern end of the primary strata. (Transects were located using a vehicle odometer that measured distance in miles). In 1989 the primary strata were sampled to distribute effort more evenly; they were subdivided according to the number of tides predicted to be lower than -0.6 m (lower low) and transects were chosen from within those sections. Sampling on the 26 days of lower low tides was divided evenly among the three primary strata. The Ninilchik stratum was sampled only at lower low tide. Sampling on the 32 low tides higher than -0.6 m was divided between Clam Gulch and the exploitation study area. Once the sample site was located along the beach a second random number between one and 50 was chosen as the first location for the sample ring to be placed in feet (the measuring tape was divided in feet) from the gravel edge of the beach (the beach topography consists, generally, of a band of gravel extending seaward gradually becoming sand and mud). The next beach level was sampled 50 feet (15.2 m) seaward of the last and so on to the furthest retreat of the water's edge. (Because of the speed at which the tide ebbs and flows it was impractical to choose beach levels independently.) The levels were resampled as the tide returned. Within each beach level, from 2 to 9 sample sites were chosen by randomly throwing the sampling ring down within reach of the hose. As many samples were taken as the ebb and flow of the tide allowed; it was necessary to keep the intake hose submerged so the pump had to be moved continually except at slack tide. A comparison of the standard deviation of clams per sample and the number of samples from the 1988 data revealed that seven samples were adequate to represent the variability at each level. Therefore, as many samples as possible up to 7 were collected at each level in 1989.

To collect a sample, the "wand" on the output hose was inserted in the substrate inside the 0.5 m^2 sample ring, pumping water into and loosening the substrate as far as the wand would penetrate, usually between 0.6 and 1.2 m in depth. The wand was repeatedly inserted and "swirled" until the entire area within the sample ring had been flushed and no clams had surfaced for approximately one minute. A hand-held net with 2 mm mesh was dragged through the loosened substrate in search of small clams not readily visible. All the clams encountered in a sample were measured and a number were sacrificed for aging. Samples were labeled with the date, sample number (each sample collected in a day was numbered consecutively), distance from the gravel's edge and number of clams in the sample. This information was also noted in a field notebook along with samples where no clams were encountered.

Initially, to determine the elevation of each beach level, a piece of reinforcing bar (rebar) was set at the top of each transect and a hand level was used to measure elevations of the beach levels relative to the rebar. During the weeks when tides were not favorable for sampling, a transit was used to determine the exact elevation of these stakes relative to benchmarks of known elevation. This information was used to relate clam density to beach elevation. To test the variability in elevation measurements determined with the transit, the lowest ebb of the tide from the gravel's edge was noted and that elevation taken from the tide book and used as a reference to determine beach level elevations. Transit measurements were found to be inaccurate ($\pm$ 0.6 m). Benchmarks referenced to different base elevations (a more precise geographic reference and one based on mean tide levels) made comparison of elevation measurements difficult. In the analysis tidal-based elevations were used to relate elevation to clam density and in 1989 a mounted builder's level was substituted for the hand level and tidal-based elevations alone were used to determine beach elevations.

In 1988, I was joined by two crew members. One crew person operated the pump, one measured clams and recorded the data and one wielded the "wand". During the 1989 field season a fourth member joined the crew to collect substrate core samples from each beach level (see Chapter 4) and conduct a creel survey at the nearest access to the beach.

Data analysis

The primary strata were considered separately in the analysis. For each primary stratum, the three-stage sampling design consisted of transects at the first stage, beach levels at the second stage, and circular samples of 0.5 m^2 at the third stage. Neither the number of beach levels among transects nor the number of samples among beach levels were equal. The primary variable examined in this study was the number of clams in a circular sample of 0.5 m^2. (To convert the estimates to a density estimate in numbers per m^2, the means and standard errors should be doubled. The coefficients of variation do not change.)

At each beach level, distance from the gravel edge and the corresponding elevation were used as second stage indices. Each was coded as shown in Appendix A, Table 18.

The three-stage sampling formulae are derived from Sukatme et al. (1988, sections 8.6, 8.10) with three assumptions: (1) sample sizes at each stage were assumed to be small compared to the total number of possible samples, therefore finite population correction factors were ignored; (2) to simplify calculations of means and variances it was assumed that the total numbers of possible samples at each stage was equal; and (3) it was assumed that the systematic random sampling at the second stage could be treated as simple random sampling for the calculation of variances. The third stage sampling unit is y_{ijk}, the number of clams sampled from the k^{th} sample at the j^{th} level of the i^{th} transect. The sample mean at each beach level is:

$$\bar{y}_{ij} = \frac{\sum_{k=1}^{n_{ij}} y_{ijk}}{n_{ij}} ,$$

with estimated variance

$$se_{ij}^2 = \frac{\sum_{k=1}^{n_{ij}} (y_{ijk}-\bar{y}_{ij})^2}{n_{ij}(n_{ij}-1)} .$$

The mean number of clams in each transect is the simple average of sample means across beach levels:

$$\bar{y}_i = \frac{\sum_{j=1}^{n_i} \bar{y}_{ij}}{n_i} ,$$

with the estimated variance across beach levels

$$se_i^2 = \frac{\sum_{j=1}^{n_i} (\bar{y}_{ij}-\bar{y}_i)^2}{n_i(n_i-1)} .$$

The stratum mean is determined by averaging over all transects:

$$\bar{y} = \frac{\sum_{i=1}^{n} \bar{y}_i}{n} ,$$

with estimated variance at this stage

$$se^2 = \frac{\sum_{i=1}^{n} (\overline{y}_i - \overline{y})^2}{n(n-1)}.$$

The total variance about the overall mean is the combination of the variance at all stages:

$$se_T^2 = se^2 + \frac{1}{n^2}\sum_{i=1}^{n} se_i^2 + \frac{1}{n^2}\sum_{i=1}^{n} \frac{1}{n_i^2}\sum_{j=1}^{n_i} se_{ij}^2.$$

The data were also stratified by either distance from the gravel edge or tidal height, ignoring the separation of sampling by transects. This assumes that the location of samples with a distance or elevation stratum is equivalent to that which would have been made by a simple random sample within the stratum. The statistical analysis is based on two-stage sampling, which is governed by the same equations as three-stage sampling omitting the third stage.

Fortran computer programs 3ST.for and 2ST.for were written by Dr. Terrance J. Quinn, II, (JCFOS, Juneau, AK) to compute the density estimates using the three- or two-stage formulae.

Results and Discussion

Six sets of analyses were made for each stratum for the 1988 data. First, three-stage estimates were calculated with distance from the gravel edge as the second-stage unit. Because elevations were not determined for all beach levels, the next two analyses used only transects for which elevations were available. The second set of analyses used distance as the second-stage unit and the third set of analyses used elevation as the second-stage unit.

As an alternative, two-stage estimators which ignore transect information were also calculated. By treating all samples taken within a distance or elevation stratum as simple random samples, a less variable estimate was possible. The mean estimate was thought to be more indicative of true density, because each distance or elevation stratum received equal weight in calculating the mean. The three-stage estimator gave equal weight to each combination of transect and beach level sampled; this tended to weight areas close to the gravel edge more heavily, because they were more available to sampling due to the nature of the tides. In the remaining three sets of estimates the two stage estimator was used to calculate density. The analyses contain distance from the gravel edge as the first stage unit, distance for which elevations were available for the first stage unit and elevation as the first stage unit, respectively.

Three-stage estimators, 1988

The first set of analyses presented are three-stage sampling estimates with distance used as the second-stage index. Estimates of mean number of clams, and standard error for all three stages are shown in Appendix A, Tables 19a, 19b and 19c, for the primary strata: Coho, Clam Gulch and Ninilchik, respectively. The overall mean numbers of clams per 0.5 m^2 sample are 0.26 for Coho, 1.16 for Clam Gulch, and 1.05 for Ninilchik. All strata contain considerable variation between first- and second-stage units. Most of the total variation is made up of variation between first-stage units (transects). In the Coho beach samples transect 5 has a mean much larger than other transects. Transect 9 in the Ninilchik stratum has a mean that is an order of magnitude larger than any other transect. As a result, the high coefficients of variation of 85% and 95% at Coho and Ninilchik beaches prevent any useful comparison of mean estimates between strata. The means between transects are not as variable at Clam Gulch because a large number of transects were sampled. As a result, the coefficient of variation is lower (27%).

The second set of analyses uses distance as the second-stage index with data where elevations were obtained (Appendix A, Tables 20a, 20b and 20c), for comparison with the third set of analyses using elevation. Elevations were not obtained from transect 1 in the Coho beach stratum, transects 4, 15, and 16 at Clam Gulch, and transect 9 at Ninilchik. Neither the mean nor the coefficient of variation at Coho and Clam Gulch change much by using the smaller data set. However, the mean of the Ninilchik stratum drops from 1.05 to 0.14 clams per sample and its coefficient of variation drops from 90% to 71%. The drop is coincident with the omission of transect 9 with a large mean density due to lack of elevation data.

The third set of analyses uses elevation as the second-stage index with the same data sets referred to in the preceding paragraph (Appendix A, Tables 21a, 21b and 21c). The mean density estimates in all strata change little by using elevation data. The coefficients of variation in the Coho and Clam Gulch strata are slightly higher by using elevation data, but the coefficient of variation is slightly lower at Ninilchik.

A summary of the estimates for the three analyses is given in Table 1, along with 80% confidence intervals about the mean density estimate. This level of accuracy is considered acceptable for reporting estimates for management applications; wider confidence limits would obscure trends in the data. These three-stage estimates are too variable to be useful for assessing population density in the three strata; in many cases, the 80% confidence intervals contain the value 0. The choice of distance or elevation as a second-stage index does not alter this conclusion.

Results reveal that the three-stage sampling plan obtains acceptably low-variance estimates of mean density only at Clam Gulch. As 16 transects were made there, a reasonable goal for sampling a section of beach of fairly uniform density would be 15 to 20 transects. For Clam Gulch, this produces a coefficient of variation of about 30% using a

Table 1. Summary of three- and two-stage sampling estimates, 1988.

Three-stage sampling estimates

Beach		Mean	SE	CV	80% C.I.'s lower	80% C.I.'s upper
Coho Beach	all distances	0.257	0.219	85.4%	-0.024	0.538
	distances subset	0.321	0.269	83.8%	-0.024	0.666
	elevations	0.276	0.247	89.3%	-0.040	0.592
Clam Gulch	all distances	1.163	0.312	26.8%	0.763	1.563
	distances subset	1.246	0.352	28.2%	0.795	1.697
	elevations	1.211	0.387	31.9%	0.715	1.706
Ninilchik	all distances	1.052	0.948	90.1%	-0.163	2.268
	distances subset	0.143	0.102	71.3%	0.012	0.274
	elevations	0.133	0.088	66.4%	0.020	0.246

Two-stage sampling estimates

Beach		Mean	SE	CV	80% C.I.'s lower	80% C.I.'s upper
Coho Beach	all distances	0.493	0.200	40.5%	0.237	0.749
	distances subset	0.550	0.202	36.7%	0.291	0.808
	elevations	0.563	0.323	57.3%	0.150	0.977
Clam Gulch	all distances	2.037	0.298	14.6%	1.654	2.419
	distances subset	2.050	0.302	14.7%	1.663	2.436
	elevations	1.249	0.366	29.3%	0.780	1.718
Ninilchik	all distances	0.713	0.211	29.5%	0.443	0.983
	distances subset	0.418	0.152	36.4%	0.223	0.613
	elevations	0.160	0.055	34.2%	0.090	0.231

three-stage sampling estimator.

Two-stage estimators, 1988

Table 1 also contains the two-stage estimates of density using transect levels, coded with the corresponding distance or elevation intervals as the first-stage units, and all samples in the stratum within the distance interval as the second-stage sampling units. Appendix B, Tables 22a, 22b and 22c, list estimates of mean number of clams and standard error for the two stages. Far less variation is present between first- and second-stage units in all three strata compared to the three-stage sampling estimators. Most variation is between first-stage units (distance intervals). The Coho stratum has 14 distance intervals represented. No clams are found at the first few intervals but density increases away from shore. The stratum mean is 0.49 clams per 0.5 m^2. The coefficient of variation, 41%, is less than half of the c.v. of the three-stage estimate. Twenty-six distance intervals are represented at Clam Gulch. Few clams are found in the first four intervals and fairly even number are found farther away from shore. The mean estimate is 2.04 clams per 0.5 m^2, with a coefficient of variation of 15%, which is close to one-half of the c.v. from three-stage sampling. Eighteen distance intervals are analyzed from Ninilchik. The mean estimate is 0.71 clams per 0.5 m^2, with a coefficient of variation of 30%, which is close to one-third of the c.v. from three-stage sampling. Density is quite variable with most of the sampling effort expended relatively close to the gravel edge.

The fifth set of analyses uses distance as the first-stage index with only data where elevations were obtained (Appendix B, Tables 23a, 23b and 23c). In the Coho and Clam Gulch strata, neither the mean nor the coefficient of variation change much by using the smaller data set. However, the omission of samples without elevation data results in a large drop in the mean of the Ninilchik stratum from 0.74 to 0.42 clams per sample and its coefficient of variation increases from 30% to 36%. The change is a result of the omission of transect 9 for which there is no elevation data and which has the large mean density.

The final set of analyses uses elevation as the first-stage index with the same data set used in the second set of analyses (Appendix B, Tables 24a, 24b and 24c). At Coho beach, the mean density estimate does not change much (0.55 to 0.56) but the coefficient of variation increases from 37% to 57% by using elevation data. This is due to a large estimate of density in elevation category 10. The mean density in the Clam Gulch stratum decreases from 2.05 to 1.25 and the coefficient of variation increases from 15% to 29%. Apparently, elevation is not as effective as distance in reducing variation. Mean density decreases from 0.42 to 0.16 and the coefficient of variation decreases slightly from 36% to 34% at Ninilchik beach. No preference for distance or elevation can be given for this stratum.

The results from two-stage sampling have lower coefficients of variation than from three-stage sampling and are preferred as the best estimates from the preliminary study in 1988 because they are stratified by beach level. Coho beach appears to have lower clam density (0.493) than Ninilchik (0.713) but the difference is not statistically significant. Both areas have lower densities than Clam Gulch (2.037). The coefficients of variation for two-stage sampling on Coho beach are very close to those for Ninilchik, and both sets of coefficients are higher than those of Clam Gulch. The lower density of clams on Coho beach reflects what was observed early in the season and in previous ADF&G studies (Nelson 1982). One densely populated bed was observed during sampling on an extremely low tide (-1.33 m) and conversations with locals indicate that a few other areas of high density occur, accounting for the higher coefficient of variation. The high coefficient of variation in Ninilchik is probably a result of the extensive area and a variable distribution of clams across the area.

The null hypothesis that clam density cannot be estimated on the eastside beaches of Cook Inlet is rejected for Clam Gulch in 1988. Samples from Clam Gulch produced acceptable estimates of razor clam density in terms of a low coefficient of variation ($\geq$30%) when stratified by distance using both 3-stage and 2-stage estimators, although 2-stage estimators are preferred. Sixteen transects were made, and variation between transects was fairly low. However, sampling at the Coho and Ninilchik strata in 1988 did not produce acceptable estimates of razor clam density. Density estimates were variable, even when two-stage estimators were used. Only 5 and 10 transects, respectively, were made in these strata.

The distribution of the mean number of all clams and harvestable sized clams ($\geq$80 mm) encountered during the two years of this study at each beach level are represented in Figures 6a-b through 9a-b. Transect locations south of Coho beach access road are found on the x-axis, the mean number of clams per 0.5 m^2 on the y-axis and distance from the gravel's edge on the z-axis. Figures 6a-b and 8a-b, contain the transects sampled in 1988. The southern boundary of the Coho stratum is indicated with a dashed line (Figure 6a-b). Many clams were accidentally discarded before they were measured during 1988 so the missing samples are not included in the harvestable population.

A large number of clams were encountered on the southern-most transect at Coho beach in 1988 (transect 5 referred to in the discussion of 3-stage estimators) (Figure 6a-b). Most of the clams at Coho beach are less than harvestable size (80 mm). A larger proportion of harvestable sized clams were sampled at Clam Gulch. The larger overall population size and smaller variability between beach levels is evident. The narrowing of the band of high densities of clams south of 21 km, discovered during sampling in 1988 (Figures 6a-b), resulted in the restratification of the Clam Gulch area in 1989. Few clams were found at Ninilchik in 1988 (Figures 8a-b). The transect (9) that contributed most

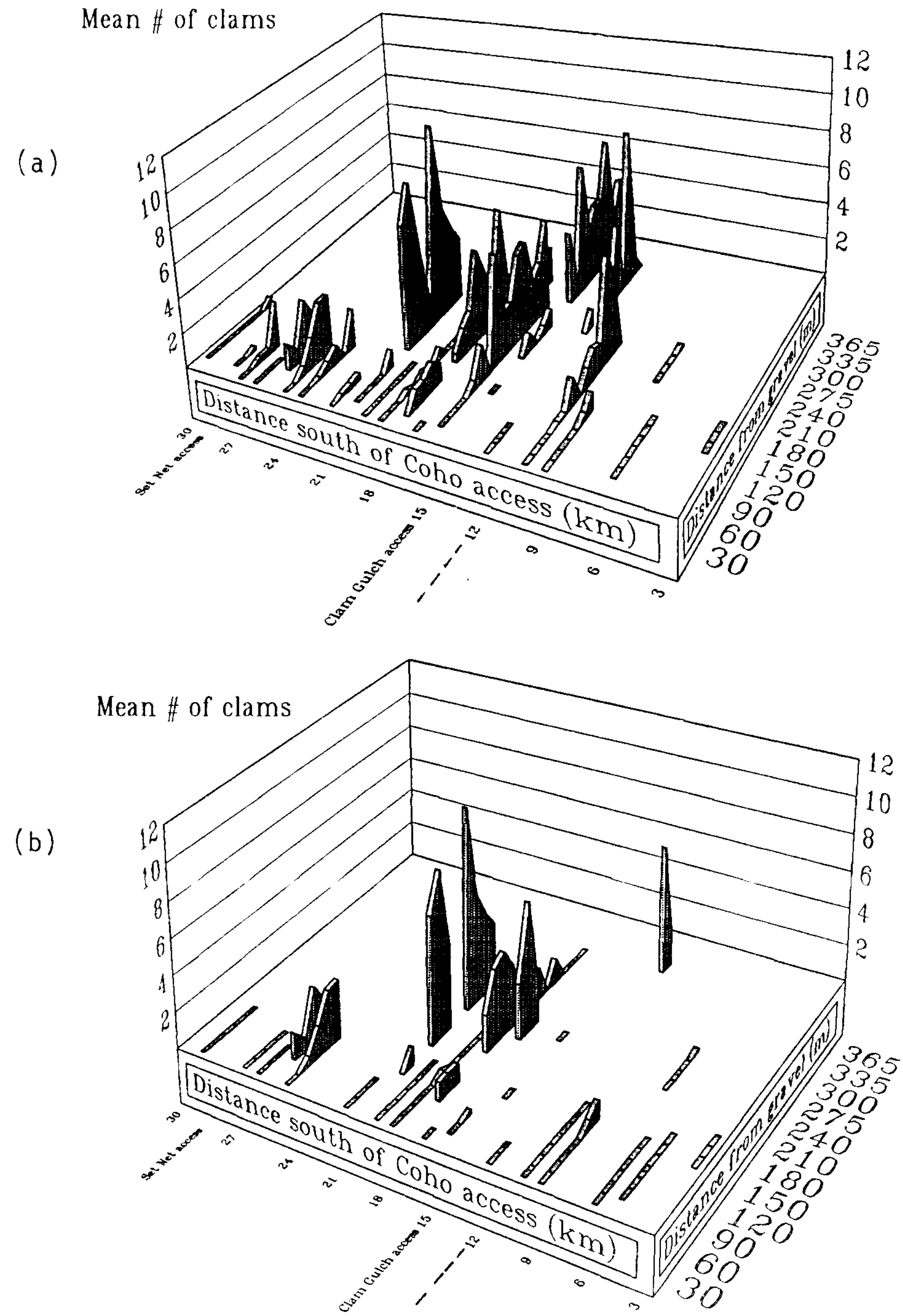
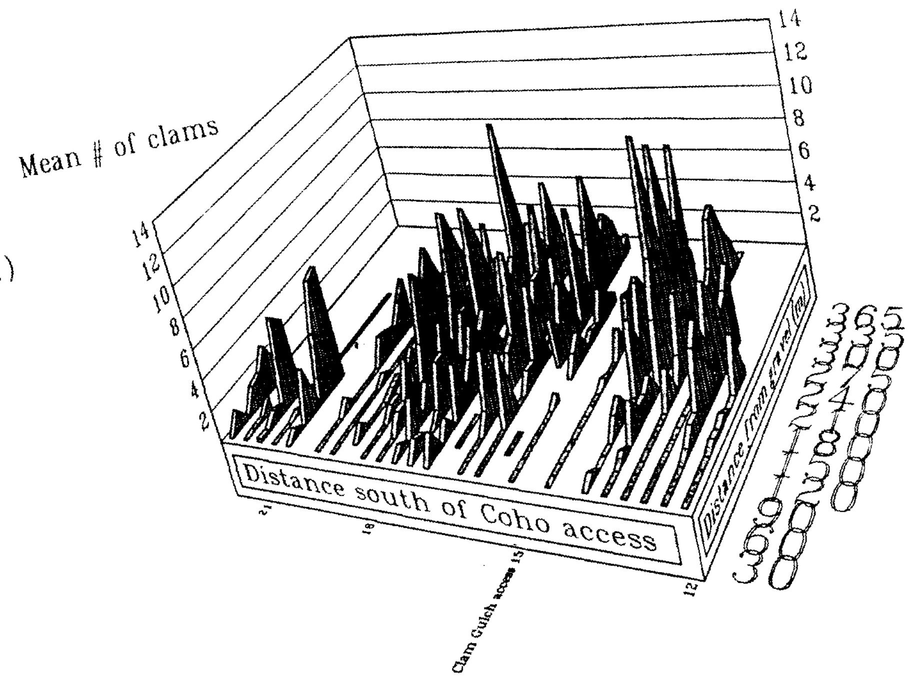


Figure 6. Mean number of (a) all clams and (b) harvestable sized ($\geq$80 mm) clams per 0.5 m^2 along transects at Coho and Clam Gulch beaches, 1988.

(a)



(b)

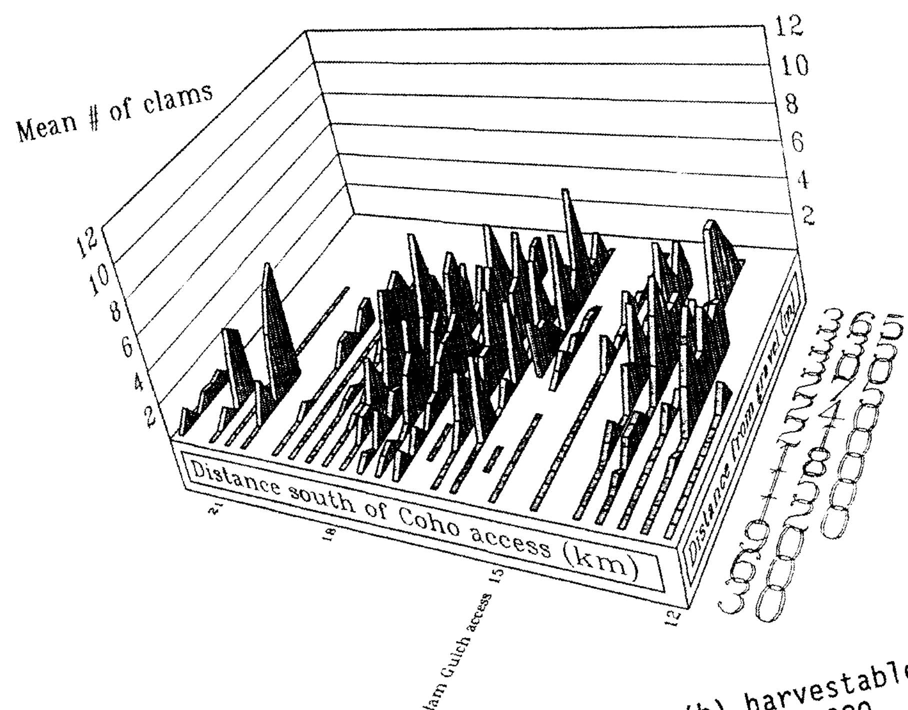


Figure 7. Mean number of (a) all clams and (b) harvestable sized ($\geq$80 mm) clams per 0.5 m^2 along transects at Clam Gulch, 1989.

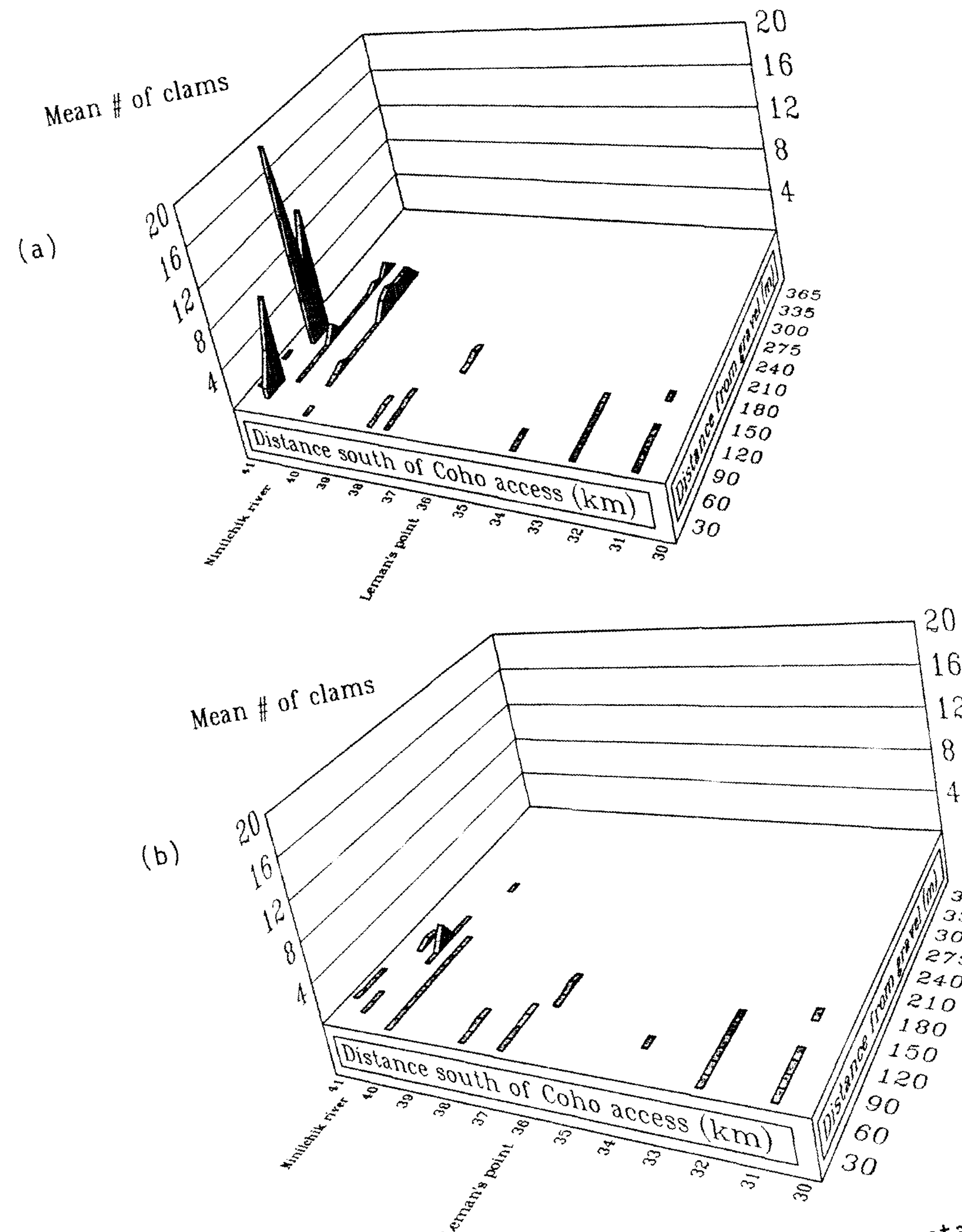
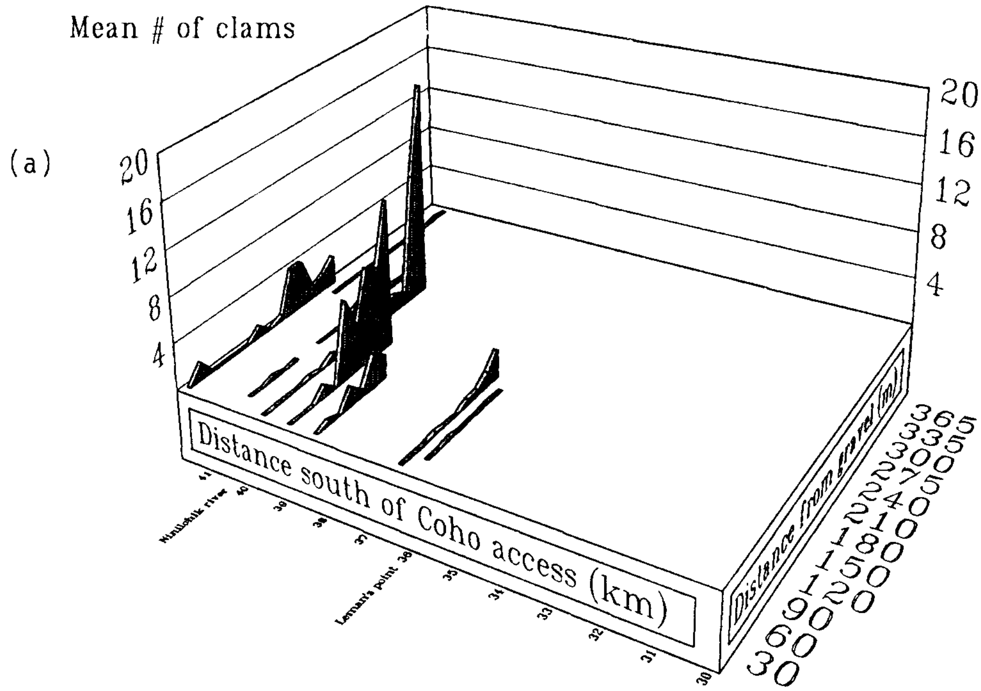


Figure 8. Mean number of (a) all clams and (b) harvestable clams ($\geq$80 mm) per 0.5 m^2 along transects at Ninilchik, 1988.



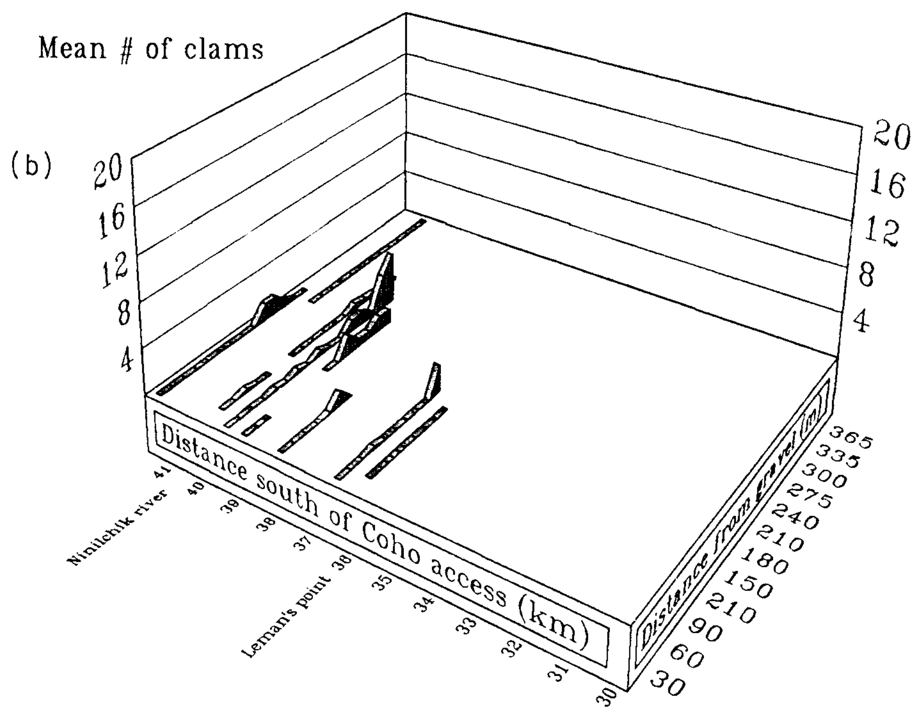


Figure 9. Mean number of (a) all clams and (b) harvestable clams ($\geq$80 mm) per 0.5 m^2 along transects at Ninilchik, 1989.

of the variability to density estimates consisted almost entirely of clams <80 mm.

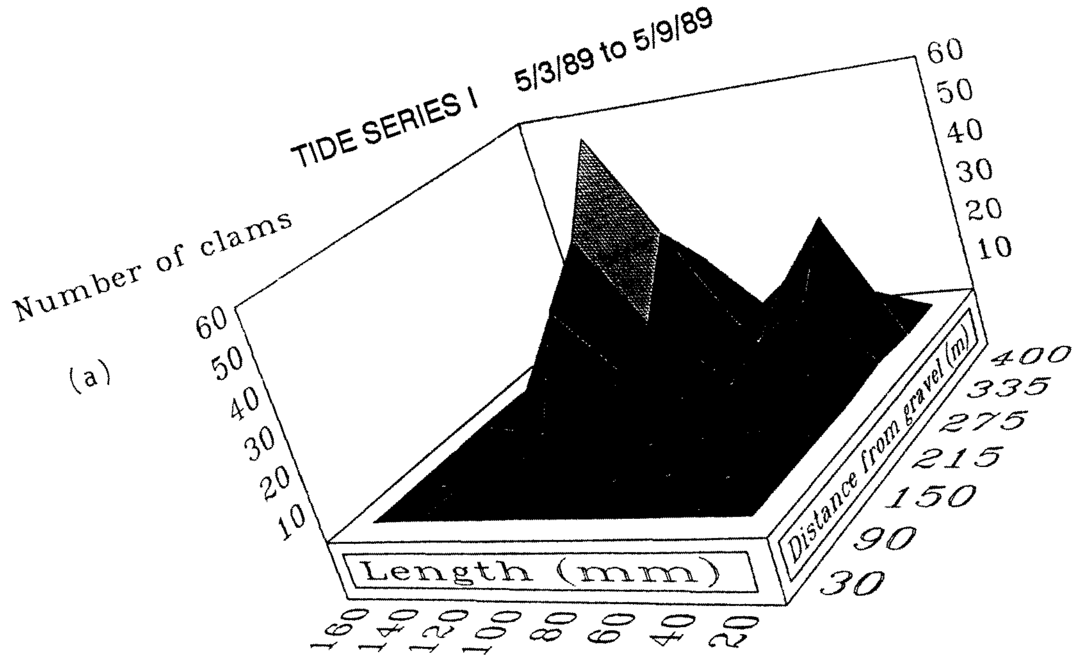
The distribution of clams at Clam Gulch appears more uniform in 1989 than in 1988 (Figures 7a-b). More clams were sampled from Ninilchik and were found throughout the Ninilchik stratum (Figure 9a-b). Most of the clams were less than harvestable size.

There appears to be a dearth of clams near the Clam Gulch Access (Figures 6a-b,and 7a-b). This area of low density was observed by McMullen (1967) who attributed it to alterations in the path of Clam Gulch creek across the beach rather than to harvest pressure, although access is easy. Few clams appear in samples near the 21 km location. A small creek flows across the beach here. Samples from the beach adjacent to the Ninilchik river contained many clams by comparison. The sparsity of clams in the Coho beach stratum may result from the influence of the Kasilof river (Nelson 1982) which enters Cook Inlet just north of the beach (Figure 1).

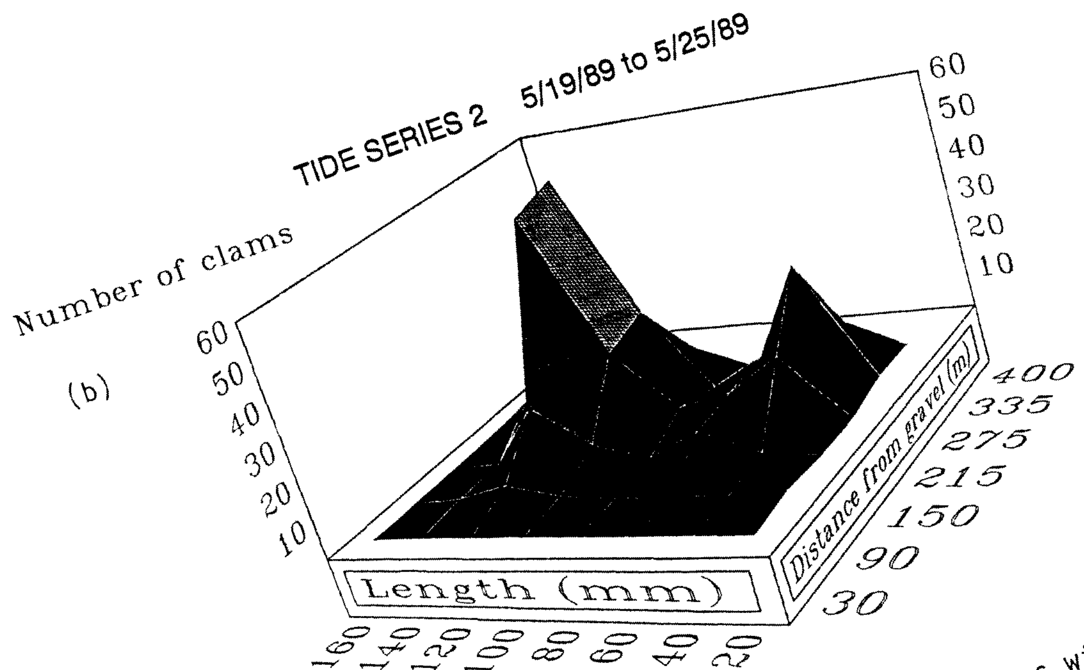
Clam density does appear to increase with distance from the gravel's edge. An examination of the change in the distribution of clam length with distance from shore at the exploitation study area reveals that the three predominate sizes of clams in our samples: 20 mm, 40-60 mm and 120 mm, are found within 215 to 335 m of the gravel's edge (Figures 10a-h). Clams in the 20 mm size range are only found beyond 275 m from the gravel's edge. This observation is not substantiated by statistical tests but may support speculation that small clams are found at lower tide levels (McMillin 1924, Lassuy and Simons 1989, Rickard et al. 1986) and that clam beds are populated by small clams migrating to higher beach levels (Ayers per. comm.).

The difference in distribution patterns between Clam Gulch and Ninilchik may result partly from the presence of coal seams which lie at

(a)

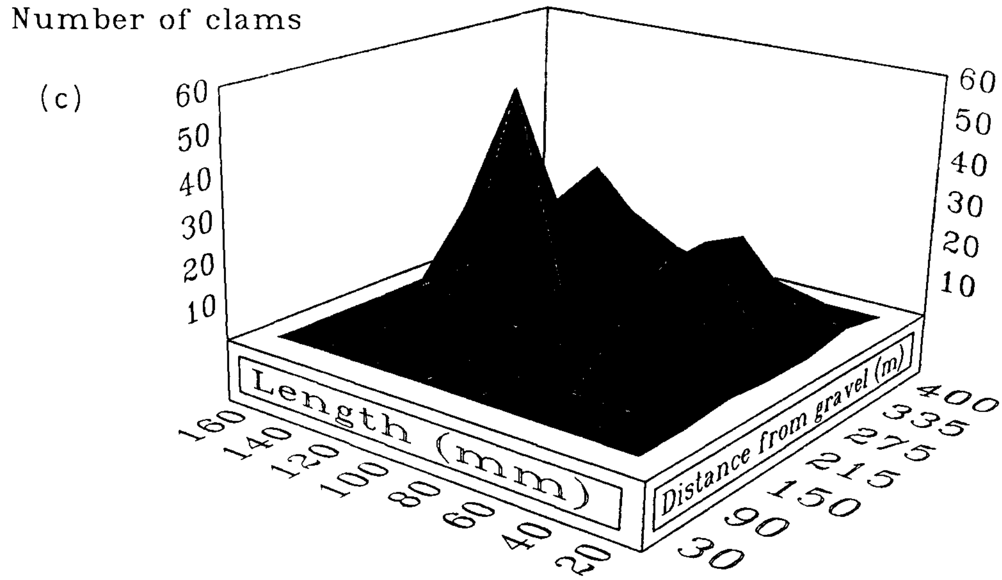


(b)

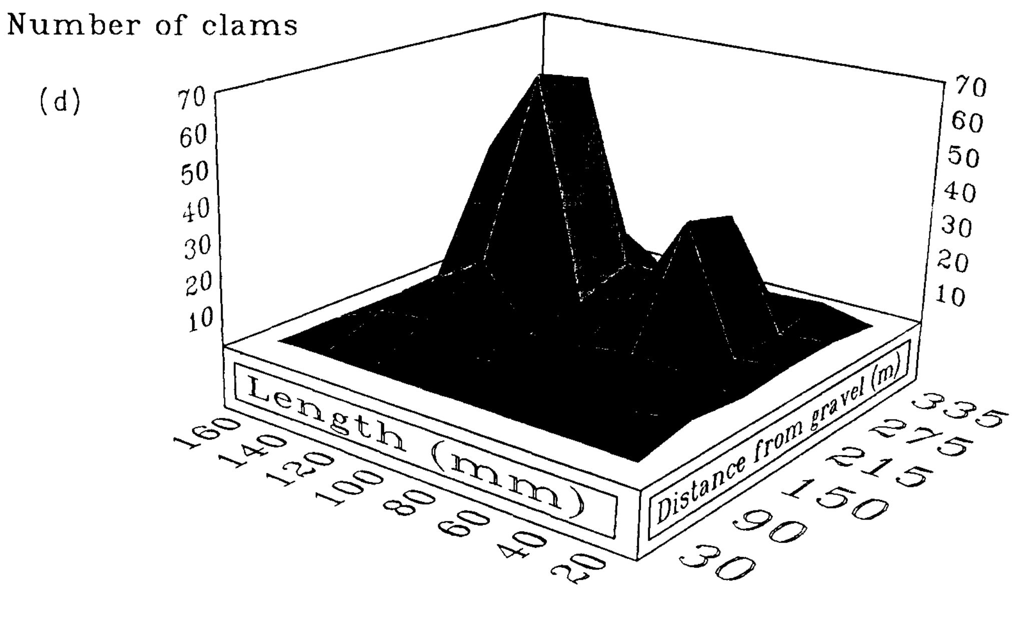


Figures 10a-h. Razor clam length frequency distributions with distance from the gravel's edge at the exploitation study area for each tide series in 1989.

TIDE SERIES 3 5/31/89 to 6/8/89

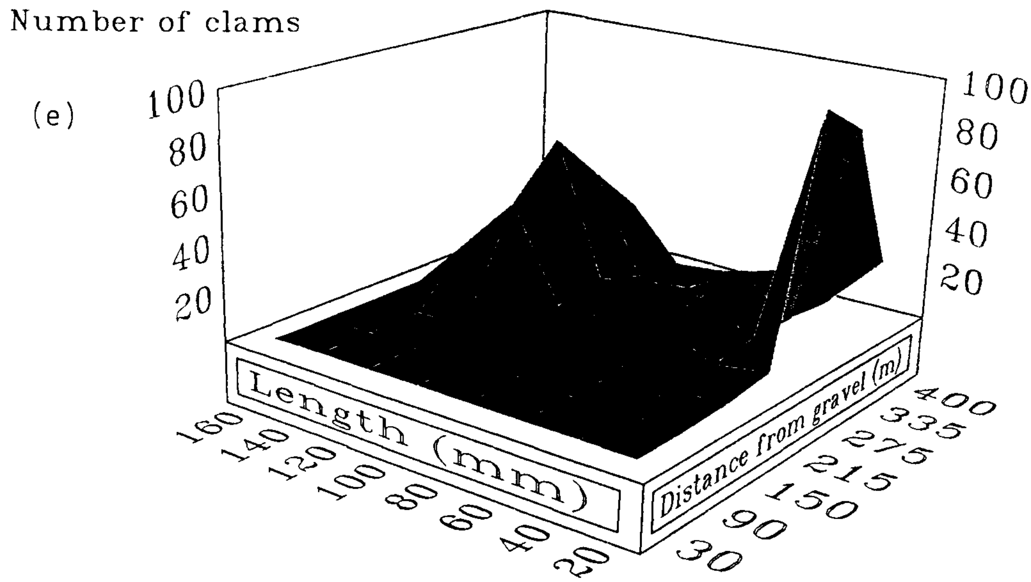


TIDE SERIES 4 6/17/89 to 6/24/89

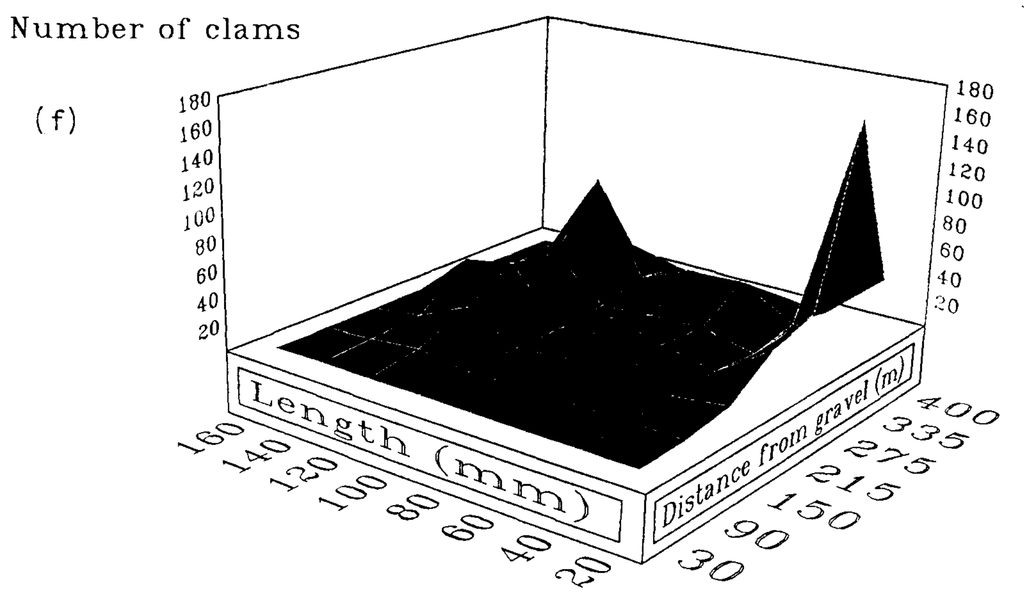


Figures 10a-h, continued.

TIDE SERIES 5 6/30/89 to 7/7/89

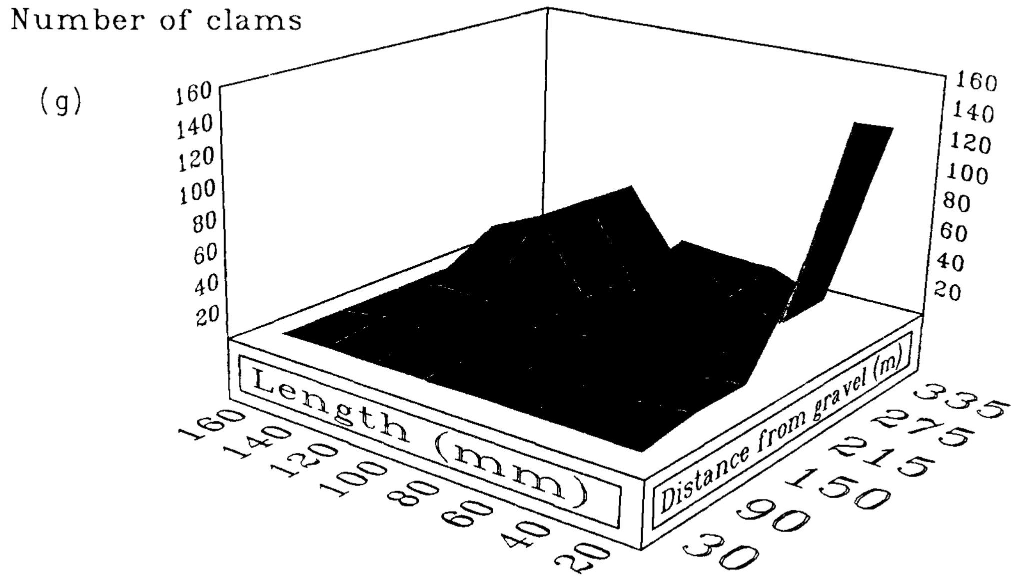


TIDE SERIES 6 7/17/89 to 7/23/89

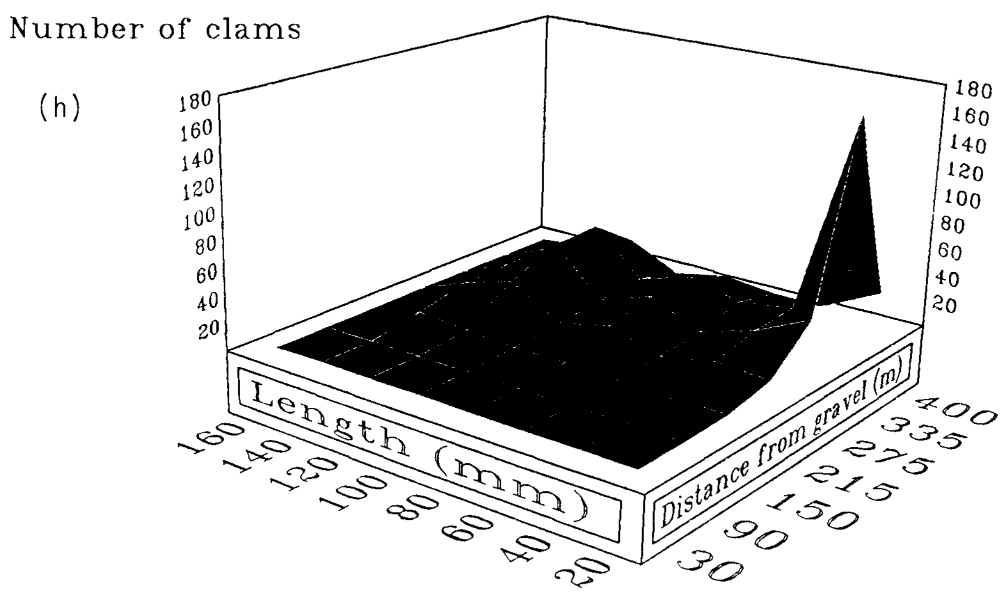


Figures 10a-h, continued.

TIDE SERIES 7 7/30/89 to 8/4/89



TIDE SERIES 8 8/15/89 to 8/20/89



Figures 10a-h, continued.

the surface or close to the surface of the Ninilchik beach. Often the sand layer is only centimeters thick for large expanses of beach. These nonexistent or shallow sand beds are interspersed with deeper pockets of sand inland and bars of sand seaward which may contain dense concentrations of clams. A large offshore bar, reached at tides lower than -0.9 m, is the major target of diggers because it contains especially dense clam beds. Shifting beds of mud may also influence clam distribution. Mud from Deep Creek and the Ninilchik river collects in patches along the beach between Leman's point and Deep Creek. The patches move, sometimes exposing or covering beds on a weekly basis. Most often they are adjacent to the gravel's edge. Coho beach and Clam Gulch, north of "21 km" are stretches of flat sand beds, 0.3 to 0.9 m deep, with scattered boulders only near creek washes. Shifting patches of mud washed from the beach bluffs occur here, as well as at Ninilchik, but remain more closely associated with the gravel's edge. South of "21 km" to Leman's point, a pattern of boulders and mud beds lie interspersed among the narrow sand bars where clams are encountered. The bars are separated from the gravel beach by a 15 to 30 m wide trough of mud approximately 0.6 m deep.

Density estimation of 1989 data using 2-stage estimators

Results from 1988 suggested that transect variability was too large for effective use of three-stage sampling. Therefore all density estimates from the 1989 data were obtained using only the two-stage estimation procedure. Three strata were sampled in 1989: Clam Gulch, Ninilchik and the exploitation study area. Four sets of analyses are presented for each strata. Density estimates with first-stage variable, distance from the gravel's edge, were calculated for all clams and for clams ≥80 mm (clams considered to be of harvestable size). Density estimates with elevation as a first-stage variable for the two size categories of clam were also calculated. The density estimates, their standard errors, coefficients of variation and 80% confidence intervals are shown in Tables 2a and 2b. The data are organized by tide period of which there were eight:

(1) series 1 - 5/3/89 to 5/9/89; (2) series 2 - 5/19/89 to 5/25/89; (3) series 3 - 5/31/89 to 6/8/89; (4) series 4 - 6/17/89 to 6/24/89; (5) series 5 - 6/30/89 to 7/7/89; (6) series 6 - 7/17/89 to 7/23/89; (7) series 7 - 7/30/89 to 8/4/89; (8) series 8 - 8/15/89 to 8/20/89.

Density with distance as a first stage variable increases during the fourth sampling period at the exploitation study area and the fifth period at Clam Gulch (Figures 11a and 12a). A decline follows the peak for both areas. The 80% confidence intervals are uniform over time. The density estimate for the entire field season is more precise than the estimates for each tide period. More clams are found in the exploitation study area than at Clam Gulch (as intended in the study design).

Approximately 60% of the population at Clam Gulch is of harvestable size ($\geq$80 mm). The proportion of harvestable clams is high early in the summer but decreases until the sixth tide series when it increases followed by a decline (Figure 11b). In the exploitation study area, the harvestable population is approximately 70% of the total until a decline in the fifth tide series (Figure 12b).

The estimated density of all clams at Ninilchik is similar to that for Clam Gulch but the estimated density of harvestable clams is much lower (Table 2a). The variability in density estimates from Ninilchik is high especially for all clams (Figure 13a). The overall estimate is less variable than the individual estimates but the variability is much higher than at Clam Gulch. No harvestable clams were collected during the first tide series. The harvestable proportion fluctuates between 50% and 20% during the remainder of the summer (Figure 13b).

The null hypothesis that clam density cannot be estimated is rejected for Clam Gulch and the exploitation study area (in terms of coefficients of variation for pooled estimates), for all clams and harvestable sized clams, when samples are stratified by distance. The use

Table 2a. Summary of two-stage sampling estimators for razor clams on eastern Cook Inlet Beaches, 1989. Number of clams per 0.5 m^2 sampling unit - stratified by distance.

	All clams					Clams ≥80mm				
				80% C.I.'s					80% C.I.'s	
Period	**Mean**	SE	CV	lower	upper	**Mean**	SE	CV	lower	upper
Exploitation study										
1	2.109	0.430	0.204	1.558	2.660	1.565	0.360	0.230	1.104	2.026
2	2.529	0.539	0.213	1.838	3.220	1.694	0.350	0.207	1.245	2.143
3	2.677	0.475	0.177	2.068	3.286	1.743	0.307	0.176	1.350	2.136
4	2.780	0.572	0.206	2.047	3.513	2.316	0.455	0.196	1.733	2.899
5	5.815	1.269	0.218	4.189	7.441	3.102	0.594	0.191	2.341	3.863
6	5.333	0.992	0.186	4.062	6.604	2.243	0.380	0.169	1.756	2.730
7	4.955	1.022	0.206	3.645	6.265	1.813	0.311	0.172	1.414	2.212
8	4.398	1.019	0.232	3.092	5.704	1.645	0.346	0.210	1.202	2.088
Pooled	3.800	0.671	0.177	2.940	4.660	1.940	0.298	0.154	1.558	2.322
Clam Gulch										
1	1.227	0.357	0.291	0.769	1.685	1.342	0.476	0.355	0.732	1.952
2	2.083	0.440	0.211	1.519	2.647	1.289	0.271	0.210	0.942	1.636
3	1.291	0.288	0.223	0.922	1.660	0.822	0.206	0.251	0.558	1.086
4	1.464	0.376	0.257	0.982	1.946	0.946	0.265	0.280	0.606	1.286
5	1.195	0.379	0.317	0.709	1.681	0.602	0.179	0.297	0.373	0.831
6	2.770	0.558	0.201	2.055	3.485	1.852	0.434	0.234	1.296	2.408
7	1.658	0.437	0.264	1.098	2.218	0.763	0.197	0.258	0.511	1.015
8	1.358	0.423	0.311	0.816	1.900	0.942	0.347	0.368	0.497	1.387
Pooled	1.630	0.221	0.136	1.347	1.913	1.025	0.148	0.144	0.835	1.215
Ninilchik										
1	0.014	0.020	1.429	-0.012	0.040	0.000	0.000	ERR	0.000	0.000
3	2.773	1.173	0.423	1.270	4.276	0.912	0.291	0.319	0.539	1.285
4	2.495	1.295	0.519	0.835	4.155	1.104	0.763	0.691	0.126	2.082
5	0.287	0.104	0.362	0.154	0.420	0.095	0.058	0.611	0.021	0.169
6	0.475	0.257	0.541	0.146	0.804	0.258	0.236	0.915	-0.044	0.560
8	1.439	0.405	0.281	0.920	1.958	0.332	0.174	0.524	0.109	0.555
Pooled	1.550	0.523	0.337	0.880	2.220	0.291	0.150	0.515	0.099	0.483

Table 2b. Summary of two-stage sampling estimators for razor clams on eastern Cook Inlet Beaches, 1989. Number of clams per 0.5 m^2 sampling unit - stratified by elevation.

	All clams					Clams ≥80mm				
				80% C.I.'s					80% C.I.'s	
Period	Mean	SE	CV	lower	upper	Mean	SE	CV	lower	upper
Exploitation Study										
1	3.226	0.577	0.179	2.487	3.965	2.224	0.421	0.189	1.684	2.764
2	3.027	1.019	0.337	1.721	4.333	2.016	0.634	0.314	1.203	2.829
3	2.135	0.696	0.326	1.243	3.027	1.447	0.453	0.313	0.866	2.028
4	3.147	0.965	0.307	1.910	4.384	2.233	0.724	0.324	1.305	3.161
5	5.862	2.301	0.393	2.913	8.811	2.698	0.919	0.341	1.520	3.876
6	6.159	1.700	0.276	3.980	8.338	2.494	0.583	0.234	1.747	3.241
7	4.919	1.589	0.323	2.883	6.955	1.905	0.512	0.269	1.249	2.561
8	5.158	1.779	0.345	2.878	7.438	1.708	0.504	0.295	1.062	2.354
Pooled	3.833	1.023	0.267	2.522	5.144	1.982	0.449	0.227	1.407	2.557
Clam Gulch										
1	0.721	0.258	0.358	0.390	1.052	0.575	0.254	0.442	0.249	0.901
2	1.802	0.542	0.301	1.107	2.497	1.034	0.319	0.309	0.625	1.443
3	0.912	0.291	0.319	0.539	1.285	0.607	0.225	0.371	0.319	0.895
4	1.127	0.423	0.375	0.585	1.669	0.706	0.308	0.436	0.311	1.101
5	0.886	0.367	0.414	0.416	1.356	0.489	0.205	0.419	0.226	0.752
6	1.680	0.628	0.374	0.875	2.485	1.060	0.482	0.455	0.442	1.678
7	0.848	0.296	0.349	0.469	1.227	0.835	0.295	0.353	0.457	1.213
8	1.517	0.666	0.439	0.663	2.371	1.067	0.542	0.508	0.372	1.762
Pooled	1.470	0.382	0.260	0.980	1.960	0.647	0.205	0.317	0.384	0.910
Ninilchik										
1	0.017	0.024	1.412	-0.014	0.048	0.000	0.000	ERR	0.000	0.000
3	2.066	1.259	0.609	0.452	3.680	0.000	0.000	ERR	0.000	0.000
4	3.851	3.029	0.787	-0.031	7.733	1.280	0.957	0.748	0.054	2.506
5	0.210	0.105	0.500	0.075	0.345	0.100	0.112	1.120	-0.044	0.244
6	0.283	0.221	0.781	-0.000	0.566	0.283	0.221	0.781	-0.000	0.566
8	0.785	0.333	0.424	0.358	1.212	0.129	0.098	0.760	0.003	0.255
Pooled	0.845	0.403	0.477	0.329	1.361	0.090	0.050	0.556	0.026	0.154

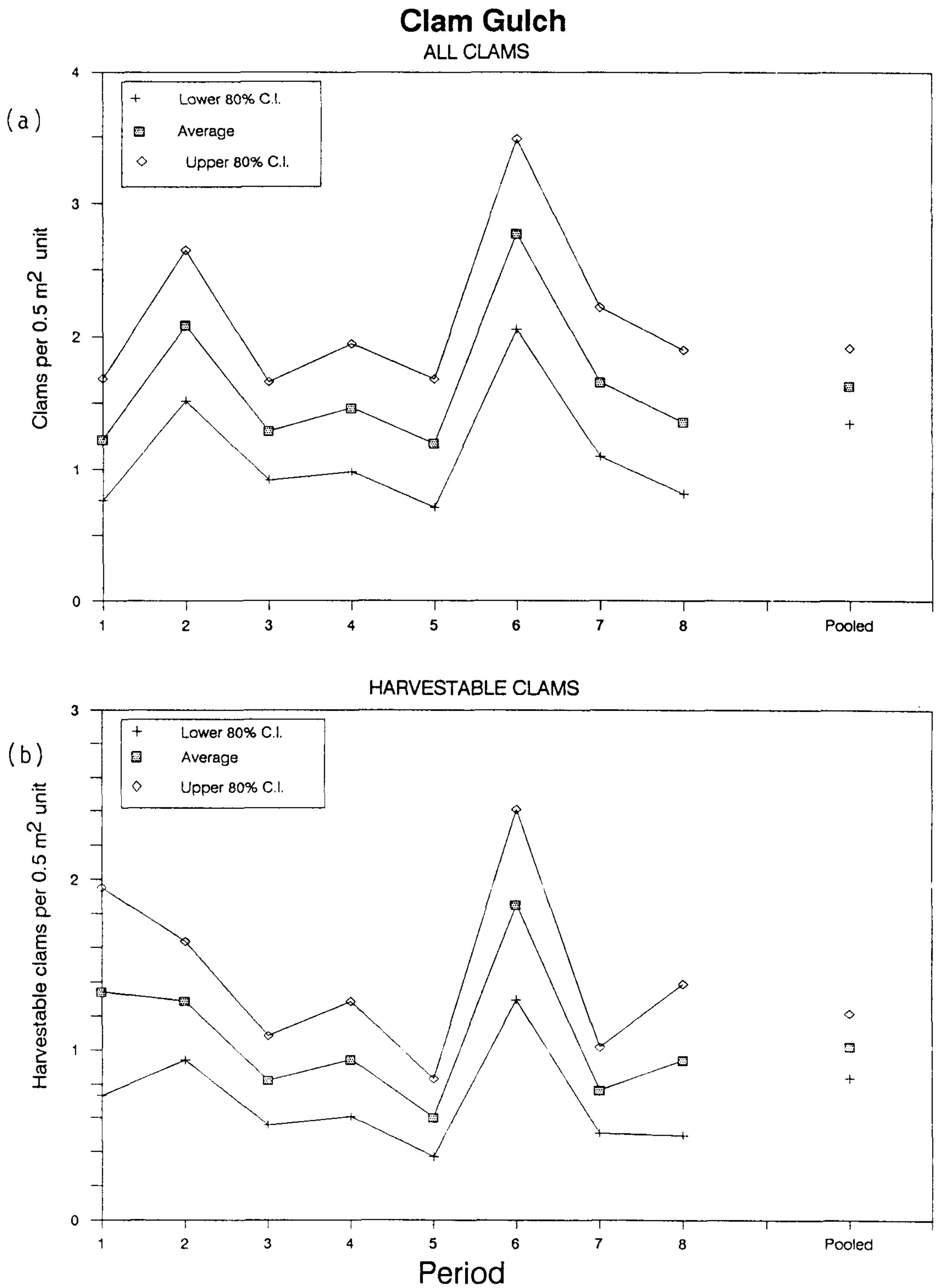


Figure 11. Mean density per tide period of (a) all clams and (b) harvestable clams ($\geq$80 mm) at Clam Gulch, 1989.

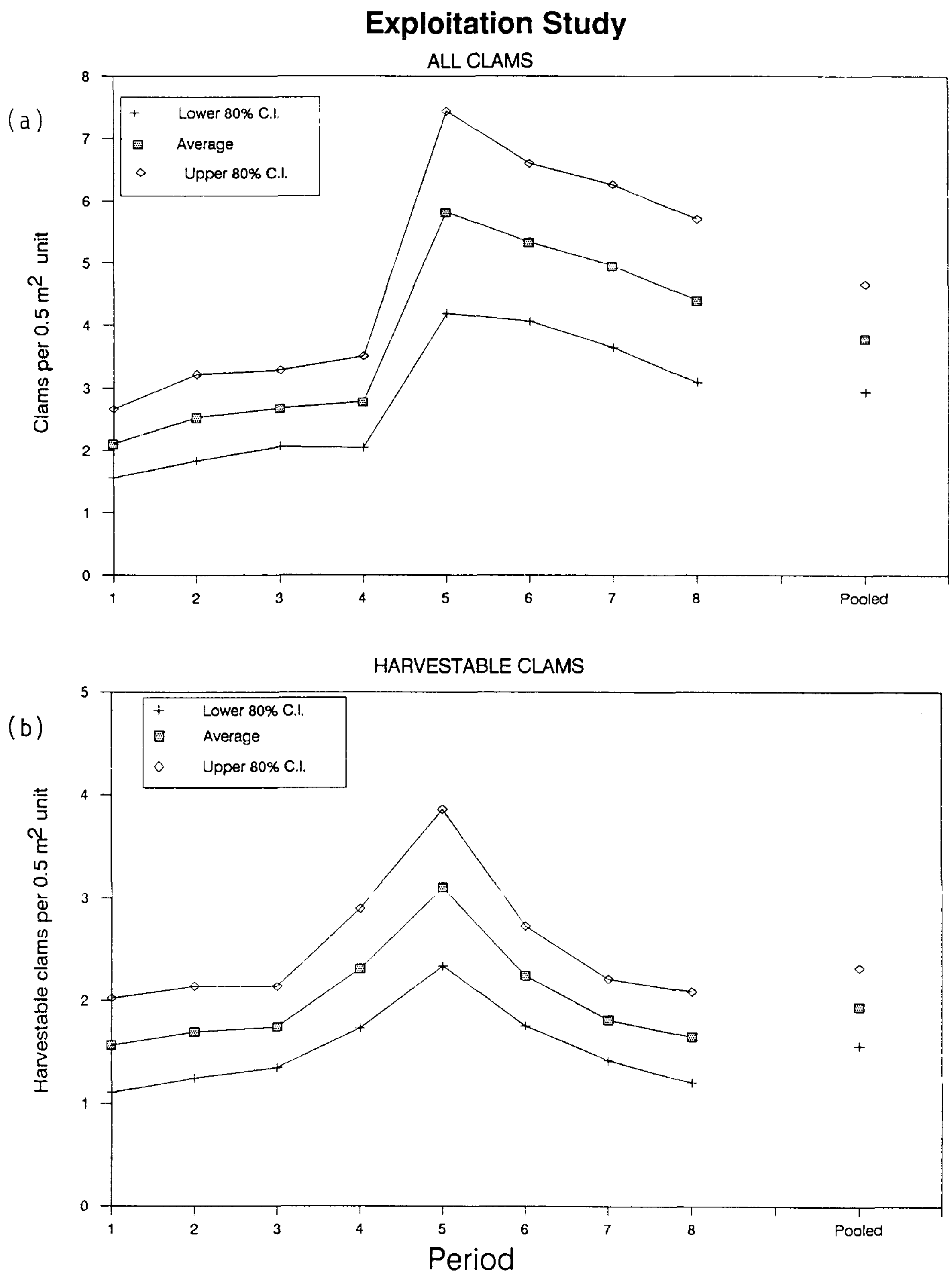


Figure 12. Mean density per tide period of (a) all clams and (b) harvestable clams (≥80 mm) at the exploitation study area, 1989.

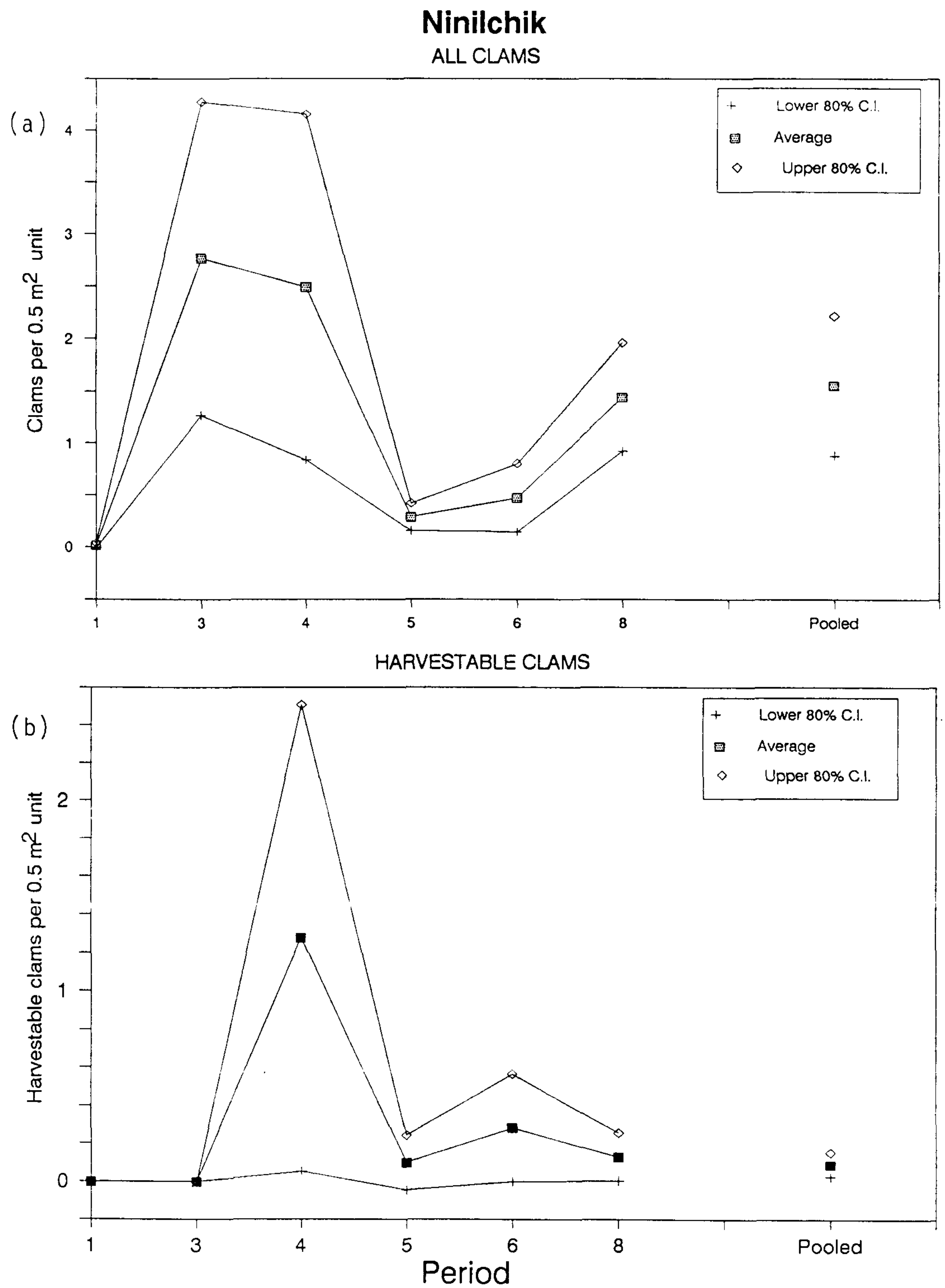


Figure 13. Mean density per tide period of (a) all clams and (b) harvestable clams ($\geq$80 mm) at Ninilchik, 1989.

of elevation does not provide an unbiased density estimate, unless weighted by area found in each elevation category. Density estimates are generally larger than those with distance as the first stage variable. Variation does not appear to be reduced using elevation, suggesting that clam density is better explained by distance (Table 2b).

There is no significant difference in the pooled density estimates for all clams stratified by distance for 1988 and 1989 at Clam Gulch (α = 0.05, z = 1.10). Due to the loss of many clams before they were measured in 1988, no exact comparison of the density of harvestable sized clams is possible between years; the omission of samples from which clam length measurements are missing would cause density to be under-estimated. However, most clams collected during 1988 were observed to be of harvestable size. An approximate pooled density estimate for harvestable clams stratified by distance from Clam Gulch in 1988 is significantly different from the pooled estimate from 1989 at α = 0.05 (z = 2.72).

Exploitation Study

The exploitation study area was sampled on 24 days during the 1989 season. There were often many diggers on the beach but few ventured near us when we sampled at the study area. The exploitation study proved to be more a "protection study"; diggers seemed to avoid the sampling crew, who were present at the study area during 40% of the clam tides. No overall negative trend in density estimates occurs either in all clams or clams $\geq$80 mm.

Creel Survey

During the summer of 1989 a creel survey was conducted each sampling day at the access point nearest the sampled site. Parties of harvesters were asked how long they dug for their clams to determine if fluctuations in density detected by the sampling crew could be related to harvest success.

Different measures of CPUE (catch-per-unit-effort) were obtained from summaries of the creel survey by area and day (Table 3). There was no need to do a special creel survey for the study area, so no CPUE statistics are available there.

Variation between periods is very low for all CPUE measures: harvest (H) per party, harvest per party hour, harvest per person and harvest per person hour, in contrast to the variation in estimates of density for both the exploitation area and Clam Gulch as a whole (Figure 14). Density estimates may be more accurate indicators of time trends because of recruitment into the fishery from growth of individual clams suggested by the length frequency data presented in Chapter 3. Estimates of harvest per person collected since 1969 (Table 4) show little variation between years. Estimates of CPUE for Clam Gulch in Table 4 vary slightly from estimates in Table 7 (Chapter 3) because of rounding errors in different ADF&G reports (Nelson 1982 and Nelson pers. comm.).

Spearman rank correlations between measures of CPUE and density were calculated to assess the interrelationship among the variables (Table 5). Correlations with absolute value greater than a critical value (0.738, Zar 1984) are significant at $\alpha = 0.05$. The CPUE measures are all significantly correlated with each other. The density estimates are not significantly correlated with each other or with the CPUE measures suggesting that CPUE and density are not both consistent measures of true clam density.

To test the null hypothesis that trends over time at Clam Gulch and the exploitation study were the same versus the alternate hypothesis that the trend at the study area was higher, regressions of the natural logarithm of harvestable clam density versus time period were made. The slope on a logarithmic scale can be interpreted as an instantaneous mortality and recruitment parameter combining the effects of natural and exploitation mortality and recruitment of harvestable clams. The

Table 3. Summary of the creel survey data collected summer, 1989.

Beach	Tide series	Total hours	No. people	No. parties	People/ party	Total clams	Catch/ person	Catch/ party	Party catch/ hour	Person catch/ hour
Clam Gulch	1	115.5	215	72	3	5,025	23	70	44	15
	2	113.0	147	57	3	3,395	23	60	30	12
	3	183.5	267	101	3	6,851	26	68	37	14
	4	115.5	177	68	3	4,956	28	73	43	16
	5	239.5	404	141	3	9,936	25	70	41	14
	6	224.0	328	112	3	10,161	31	91	45	15
	7	207.0	280	110	3	7,643	27	69	37	15
	8	81.5	125	48	3	2,288	18	48	28	11
	Total	1279.5	1943	709		50,255				
Ninilchik	1	19.8	38	16	2	1,089	29	68	55	23
	3	94.0	146	50	3	2,469	17	49	26	9
	4	59.5	84	35	2	1,832	22	52	31	13
	5	44.0	77	30	3	2,128	28	71	48	19
	6	54.3	91	31	3	2,272	25	73	42	14
	8	61.3	115	42	3	2,610	23	62	43	16
	Total	332.8	551	204		12,400				

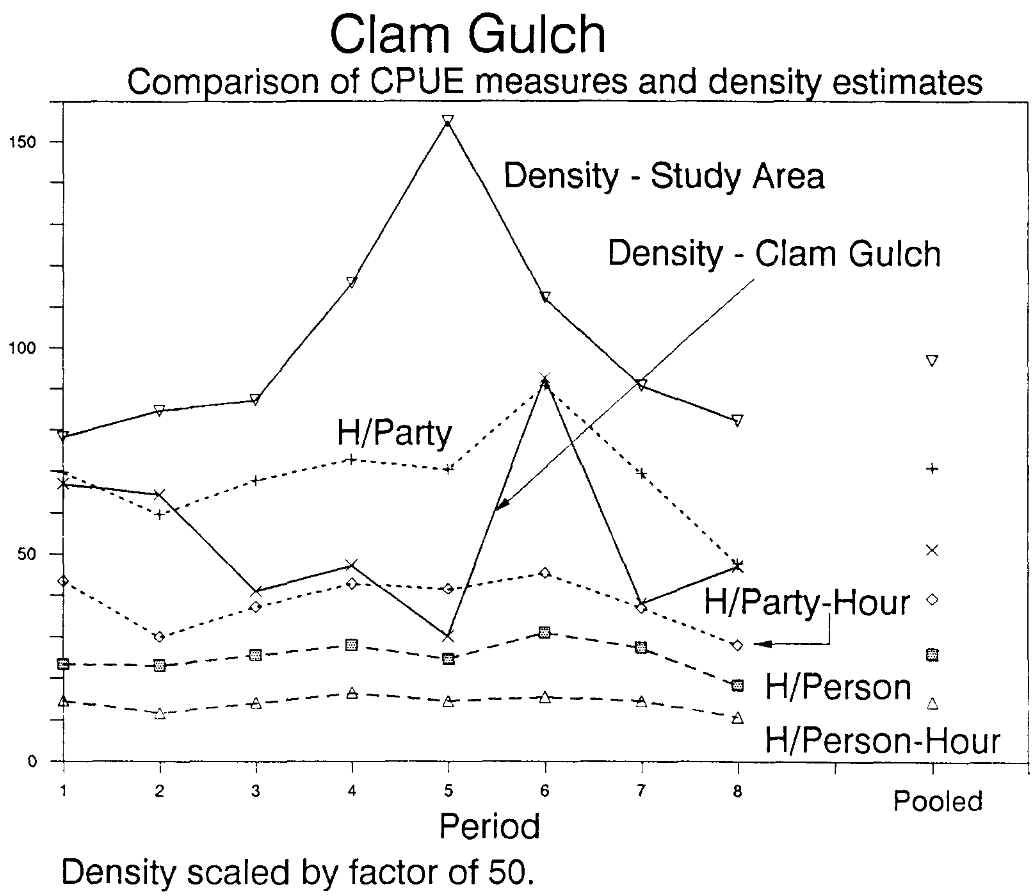


Figure 14. Catch-per-unit-effort compared with estimates of harvestable clam density from sampling at Clam Gulch, 1989.

Table 4. Harvest and effort, eastside Cook Inlet beaches 1969-1989.

	CPUE		Eastern Cook Inlet Total	
Year	Clam Gulch	Ninilchik	Effort (Digger-Days)	Harvest
1969	31.3		12,200	375,800
1970	29.6		11,370	314,650
1971	29.5		6,800	187,760
1972	34.1		15,400	437,530
1973	36.1		23,770	682,600
1974	34.6		27,410	872,450
1975	38.1		24,260	896,080
1976	35.0		29,320	939,000
1977	34.8		25,390	871,200
1978	30.0		29,750	896,700
1979	29.2		30,320	996,700
1980	26.6		31,490	771,600
1981	28.9		31,300	829,400
1982	30.1		31,950	964,000
1983	31.2		31,470	978,720
1984	34.9		29,880	1,044,300
1985	34.3		31,200	1,068,340
1986	34.8		32,500	1,124,730
1987	38.3	33.4	25,400	979,020
1988	32.4	30.4	30,900	1,171,308
1989	25.9	22.5	18,900	832,155

Table 5. Matrix of Spearman rank correlation coefficients for measures of CPUE and density, Clam Gulch, 1989.

	PER	CI	CP	CPH	CIH	CG	SA
PER	1.000						
CI	0.143	1.000					
CP	-0.048	0.810*	1.000				
CPH	-0.310	0.667	0.905*	1.000			
CIH	-0.143	0.810*	0.905*	0.857*	1.000		
CG	-0.357	0.199	0.262	0.476	0.357	1.000	
SA	0.286	0.667	0.667	0.333	0.452	-0.381	1.000

NUMBER OF OBSERVATIONS: 8

PER: Period index (1,...,8)
CI: Harvest per individual person
CP: Harvest per party
CPH: Harvest per party hour
CIH: Harvest per individual person hour
CG: Density estimate at Clam Gulch from sampling
SA: Density estimate at the study area within Clam Gulch from sampling

An asterisk denotes a significant correlation. The critical value for a significant correlation at $\alpha = 0.05$ is 0.738 from Zar (1984).

estimated slope for Clam Gulch is -0.0371 ± 1 s.e. of 0.0580. For the study area the estimate of slope is 0.027 ± 1 s.e. of 0.0379. Neither estimate is significantly different from zero. Therefore, the null hypothesis was accepted and I concluded that trends in density within the exploitation study area were not significantly different from the rest of Clam Gulch beach.

A one-sided test for equality of slopes (Zar 1984, p. 228-229) was made to determine if a slight increase in density observed at the study area was different from the small decrease in density at Clam Gulch as a whole. The test statistic $t = 0.834$ is not significant $(0.10<P<0.25)$ suggesting that trends in the harvestable populations of the two areas are the same over time.

Estimates of density for all clams at Clam Gulch were not significantly different between years. Nor was there a significant difference between the exploitation study area and Clam Gulch in the trends of density estimates over the 1989 field season. This suggests that harvest did not have a detectable effect on the abundance of clams at Clam Gulch in 1989. There was a significant difference in the density of harvestable sized clams between years. This may be a result of sampling variability; the change of stratum boundaries between years (Figures 3 and 4) eliminated much of the variability in the habitat within the stratum. In addition, fewer transects are represented in the 1988 estimate. The decline may reflect the influence of the clams <80 mm included in the density estimate in 1988. Or it may indicate that diggers have affected the density of clams at Clam Gulch in 1988; results are not conclusive in the face of the uncertainty in the estimate of harvestable clams in 1988 caused by the loss of clam measurements.

Highly variable densities of clams were measured at Ninilchik suggesting the irregular distribution of clams described earlier. Few harvestable clams were found indicating that perhaps sampling effort was insufficient, an alternative stratification scheme is needed, a low density of harvestable clams exists or a combination of these factors.

Population parameter estimation

An estimate of the total population can be made with knowledge of the population area. The area of each primary stratum was estimated by multiplying the length of each transect by half the length of the beach between that transect and the adjacent transects. The individual area measurements were summed to estimate the total beach area within the stratum.

Due to uncertainties in the estimates at Coho, a total population estimate was not calculated. For this same reason estimates reported for Ninilchik are of little value. An estimate of the harvestable population at Clam Gulch was not possible in 1988. However, since most clams sampled at Clam Gulch in 1988 were observed to be of harvestable size the pooled estimate of density for all clams is reported. The area of Clam Gulch stratum in 1988 is 3.454 million m^2 (Table 6). Multiplying this by the point estimate of 2.037 clams per 0.5 m^2 (4.047 per m^2) results in a population estimate of 14.068 million clams at Clam Gulch. Similarly, the 80% confidence interval of 1.65 to 2.42 clams per 0.5 m^2 translates into a population confidence interval of 11.427 to 16.710 million clams. The area of the Clam Gulch stratum is 1.513 million m^2 in 1989. Transects from within the area sampled in 1989, are used to determine an estimate in 1988 for comparison between years. The density of clams is 1.985 per 0.5 m^2 in the smaller area in 1988. The total population is 6.012 million clams with an 80% confidence interval of 4.765 to 7,258 million clams. In 1989 the density at the Clam Gulch sampling area is 1.025 clams per 0.5 m^2 for a total population estimate of 3.676 million clams, 80% confidence interval (2.530 to 3.676 million).

An estimate of harvestable sized clams for Ninilchik in 1988 is determined by leaving out transect 9 in 1988 and is compared to the

Table 6. Density and population estimates of harvestable clams from 2-stage estimator (stratified by distance).

Beach	Year	Area (m^2)	Mean # clams/m^2	SE	80% C.I. lower	80% C.I. upper	Population size	80% C.I. lower	80% C.I. upper
CG	1988	3,453,339	4.074	0.597	3.309	4.398	14,068,902	11,427,407	16,710,397
*CG	1988	1,513,357	3.973	0.643	3.149	4.796	6,012,018	4,765,926	7,258,109
CG	1989	1,513,357	2.05	0.295	1.672	2.429	3,102,703	2,529,614	3,675,793
EXP	1989	329,772	3.88	0.595	3.116	4.643	1,279,366	1,027,659	1,531,072
NI	1988	1,108,435	0.894	0.308	0.499	1.226	990,941	552,748	1,429,133
NI	1989	1,108,435	0.582	0.300	0.198	0.966	645,109	219,470	1,070,748

CG: Clam Gulch
EXP: Exploitation study area
NI: Ninilchik

*These are estimates for the area chosen as the Clam Gulch strata in 1989.

density of harvestable size clams in 1989 (Table 6). Individual estimates of abundance are extremely variable, imparting little information about the population size.

The decline in the number of clams at Clam Gulch has been discussed in the section of this chapter entitled "Creel Survey". The exploitation study demonstrates that diggers had no significant effect on the density of clams at Clam Gulch in 1989, however more diggers were present on the beach in 1988 and could have affected clam abundance. The cause(s) of the decline could be environmental, but the scope of my research was limited to the measurement of temperature and salinity at the time of sampling only and does not allow me to speculate about climatic changes which may have caused higher mortality in 1988. It is more likely that the decline in the density estimates is an artifact of sampling or the data lost in 1988. Trends in estimates of abundance from length-age analyses to be presented in Chapter 3 are opposite of the trends in density estimates.

Razor clam quiche
(Serves 4)

1 c fresh, frozen or canned razor clams, sliced
1/4 c chopped onion
1 c sliced mushrooms, broccoli and/or spinach
1/4 c milk
1/2 c cheddar cheese
2 eggs
2 large garlic cloves, grated or pressed
1 t dill
salt
oil
1 uncooked pie shell

Cook the garlic and dill in oil over low heat. Increase the heat and add the clams, stirring quickly for 1 minute. Remove the clams from the pan and save them. Add the onion and vegetables to the pan. Cook them to half the desired tenderness, salt them to taste and remove the mixture from the heat. Mix the eggs, milk and half of the cheese in a separate bowl and combine them with the vegetables and clams. Add the combination to the pie shell. Sprinkle the remaining cheese over the top of the pie. Bake in a preheated oven at 375° F for 30 minutes or until the top is golden brown.

CHAPTER 3

POPULATION ESTIMATION FROM LENGTH-AGE ANALYSIS

This chapter presents information on length frequencies and age-structure for a more detailed examination of the population characteristics of razor clams on Eastside beaches. Age-structured data are analyzed to determine if estimation of the population size is possible with catch-age analysis using auxiliary information (Deriso et al. 1985, 1989). Such analysis provides estimates of abundance and fishing mortality by age and year.

Length frequencies are used to determine ages of razor clams from beaches along the Washington coast. Tegelberg (1964) and Douglas Simons (pers. comm.) cite reasons for this: Washington razor clams grow rapidly and do not form clear annuli, temperate weather conditions cause the formation of indistinct annuli, and few age classes (1 to 3) are present in Washington clam populations. Growth of the Alaskan razor clam is much slower and the contrast between seasons is much greater. Clams older than 17 years may be present in northern populations. For these reasons age determination by annuli is preferred for northern populations.

Annuli (circuli) are darkened concentric ridges, formed in the calcareous and silicious body parts of many animals during periods of slowed growth, commonly used in age determination. Severe winters cause distinct annuli to form on the external shell surface of Alaskan razor clams. The use of these annular rings for age determination has been challenged and supported (Nelson 1982). Storms, extreme low tides, fresh water and spawning can slow growth causing the deposition of excess shell material that mimics winter growth annuli (Weymouth and McMillin 1931, Hirschhorn 1962). Many shells lack an annulus indicating the first winter of life (Nickerson 1975). Weymouth and McMillin (1931) noted that the second annulus was also difficult to discern. McMullen (1967) felt it was impractical to age clams from the Eastside beaches older than five years.

Nelson (1982) found that the first annulus was indistinguishable on most razor clams from the Eastside beaches. I observed that the first annulus is generally absent and that the second annulus, though prominent in clams up to four years old, was often indistinguishable in older clams. The growth rings of clams more than six years of age were often difficult to distinguish because they are crowded on the outer extremes of the shell. Nelson (1982) felt that in spite of problems the shell circuli are the best indicators of razor clam age on Eastside Cook Inlet beaches.

I sectioned razor clam shells through the hinge with an Isomet lowspeed saw equipped with diamond tipped blades to examine the growth increments in the internal shell structure (Douglas Simons, pers. comm.). The brittle shells chipped and I was unable to get a uniformly thin section. Growth rings were visible only in the thinnest parts of the sections.

Data on age composition and length frequency have been collected consistently from two areas on Eastside beaches, Clam Gulch and Oil Pad Access, since 1965. In 1965-1966, the method of collection is not known. In 1967, sampling was conducted from established points at the two areas several times during a summer and sampling was conducted to dig all shows of clams until a desired sample size of 100 clams was obtained. Nelson (1982) felt that reliable information existed from Clam Gulch from 1969. I found inconsistent interpretations of first annulus length in 1976 and therefore chose to begin my analysis with clams aged from 1977 to 1987.

Aging techniques

A systematic random sample of clam shells was collected during 1988 and 1989 from the clams sampled by the methods described in Chapter 2 to be used in age determination for those years. I was instructed by ADF&G biologists familiar with aging techniques using annuli, to learn their methods to provide continuity between this and earlier studies. Clam shells were soaked in bleach to expose annuli more clearly as recommended in Nelson (1982). The annuli were examined under a high intensity desk magnifying lamp or dissecting microscope. The width of the annuli were measured along the long axis of the shell with a vernier caliper.

Estimation of age-structure

The slope of a regression of harvest estimates from all Eastside beaches from postal questionnaires and harvest estimated from a creel survey for 1977 to 1980 was significantly different from zero ($t = 10.3$, $R^2 = 0.98$) indicating that the two sources are equally reliable (Table 7). Therefore the estimated harvest was obtained from postal questionnaires (Mills 1977..1989).

Since 1966, aerial surveys have been conducted by ADF&G to obtain estimates of effort for the different management areas on Eastside beaches (Figure 1). Data are considered to be reliable since 1971. Estimates of relative effort (the average number of diggers on a beach during a summer divided by the total number of diggers counted during a summer) from 1977 to 1989 were adjusted by relative success rates at each management area. Harvest success at Whiskey Gulch, Happy Valley and Coho Beach Management areas (Figure 1) was assumed to be half of that at the Clam Gulch, Ninilchik and Set Net Access areas. The adjusted relative catch is calculated as the product of the harvest success and relative effort, expressed as a proportion (Table 8). The harvest by beach is a product of the adjusted relative catch and the total harvest from the mail-in harvest survey (Table 8).

Nelson (1982) found age composition to be similar between Oil Pad Access (an essentially unexploited beach) and Clam Gulch (the major clamming beach in the area). Thus he concluded that exploitation did not have a major effect on the age composition and length distribution of the population. Based on this assumption, clams sampled throughout each field season were pooled to determine age composition.

Table 7. Inventory of harvest data at Clam Gulch and eastside Cook Inlet harvests, and inventory of sample size of clams collected for age and length determination at Clam Gulch since 1969.

	Clam Gulch				Statewide Harvest Survey		
Year	Harvest	Effort	CPUE	Number Sampled	Harvest	Effort (digger-days)	CPUE
1969	279,480	8,580	32.6	742			
1970	234,350	7,810	30.0	655			
1971	126,260	4,270	29.6	688			
1972	259,560	7,860	33.0	715			
1973	392,140	11,100	35.3	824			
1974	596,110	17,550	34.0	480			
1975	607,850	15,710	38.7	504			
1976	708,670	20,850	34.0	744			
1977	710,050	21,160	33.6	443	871,247	25,393	34.3
1978	729,490	23,580	30.9	492	896,667	29,750	30.1
1979	765,690	26,430	29.0	546	966,677	30,323	31.9
1980	623,800	23,560	26.5	348	771,603	31,494	24.5
1981				381	829,436	31,298	26.5
1982				204	963,994	31,954	30.2
1983				116	978,720	31,470	31.1
1984				150	1,044,307	29,880	35.0
1985				65	1,068,340	31,195	34.2
1986				94	1,124,730	32,500	34.6
1987				109	979,020	25,427	38.5
1988				122	1,171,308	30,905	37.9
1989				112	832,155	18,894	44.0

Table 8. Estimated relative effort and harvests at eastside Cook Inlet beaches 1977-1989.

Relative effort from aerial surveys

Year	Coho	Clam Gulch	Oil Pad	Ninilchik	Happy Valley	Whiskey Gulch
1977	0.041	0.661	0.105	0.107	0.058	0.028
1978	0.033	0.699	0.096	0.065	0.081	0.026
1979	0.046	0.714	0.068	0.069	0.088	0.015
1980	0.035	0.570	0.132	0.084	0.140	0.038
1981	0.029	0.529	0.111	0.096	0.177	0.059
1982	0.019	0.394	0.087	0.109	0.292	0.099
1983	0.028	0.394	0.104	0.128	0.244	0.102
1984	0.011	0.368	0.150	0.205	0.190	0.077
1985	0.015	0.302	0.151	0.269	0.218	0.046
1986	0.005	0.279	0.150	0.264	0.215	0.087
1987	0.003	0.190	0.116	0.458	0.167	0.065
1988	0.013	0.226	0.042	0.461	0.194	0.064
1989	0.004	0.265	0.111	0.464	0.105	0.051

Estimated harvest

Year	Coho	Clam Gulch	Oil Pad	Ninilchik	Happy Valley	Whiskey Gulch	TOTAL
1977	19,072	614,943	97,684	99,545	26,979	13,025	871,247
1978	15,909	673,946	92,559	62,670	39,048	12,534	896,667
1979	24,023	745,767	71,025	72,070	45,958	7,834	966,677
1980	15,129	492,788	114,119	72,621	60,518	16,426	771,603
1981	13,848	505,206	106,007	91,682	84,519	28,173	829,436
1982	11,519	477,753	105,494	132,170	177,035	60,022	963,994
1983	17,009	478,674	126,350	155,508	148,219	61,960	987,720
1984	6,663	445,829	181,724	248,356	115,092	46,642	1,044,307
1985	9,301	374,508	187,254	333,585	135,170	28,522	1,068,340
1986	3,322	370,703	199,302	350,772	142,833	57,798	1,124,730
1987	1,666	211,020	128,833	508,668	92,738	36,095	979,020
1988	8,807	306,207	56,906	624,607	131,425	43,357	1,171,308
1989	1,809	239,697	100,401	419,696	47,487	23,065	832,155

A sample size of three hundred clams was determined to be adequate to achieve a population estimate of the appropriate precision and accuracy based on studies by Quinn et al. (1983) and Lai (1987) and reported in Quinn and Jones (1989). More than three hundred clams were collected from Clam Gulch each year prior to 1980. Between 50 and 200 clams were collected after 1981 (Table 9); less than the number needed to achieve reliable population estimates.

Age composition was determined using the FORTRAN computer program AGE.for written by Quinn (pers. comm.) which calculates age composition for two-stage sampling in the manner of Quinn et al. (1983). Only clams larger than 79 mm (age 4) were used in my analysis because this was the size that clams were thought to be fully vulnerable to diggers. Clams older than ten were pooled into an "11+" age category. The estimate of total catch from Clam Gulch obtained from the aerial survey was then multiplied by the relative frequency of clams in each age class to obtain an age-specific estimate of harvest (Table 10). The method is described by Nelson (1982), who obtained catch estimates for prior years.

An alternative method of constructing age-length keys was examined. It is not correct to simply pool age-length data from years with reliable age composition data and apply them to other years because bias in age composition estimates occurs (Clark 1981). One method for using age-length keys for other data is a regression approach (Clark 1981). This approach was attempted to provide better age composition estimates. Absence of some ages in various years made matrix arithmetic impossible, however.

There has been an overall decline in harvests at Clam Gulch since 1977 (Tables 8 and 10) as a result of low levels of effort (Table 8). The disappearance age-classes 9+ from the harvest at Clam Gulch since 1986 (Table 10) could be interpreted as an indication that the population is over-harvested despite low levels of effort. The disappearance of the oldest age-classes from the harvest may result, in part, from the small

Table 9. Number of clams sampled for aging at eastside Cook Inlet beaches since 1981.

Year	COHO	CG	OPA	SNA	NIN	DPC	STAR	Total
1981		381	198					579
1982		204	140					344
1983		116	132					248
1984		150	72					222
1985	100	65	82	71	85	0	46	449
1986	98	94	91	71	88	64		506
1987	99	109	92	78	91	81		550
1988		122						122
1989	105	112	109	110	149	103		688

COHO: Coho Beach
CG: Clam Gulch
OPA: Oil Pad Access
SNA: Set Net Access
NIN: Ninilchik
DPC: Deep Creek Access
STAR: Starisky Creek (Whiskey Gulch)

Table 10. Estimated harvest by age-class, Clam Gulch, 1977-1989.

	Age							
Year	4	5	6	7	8	9	10	11+
1977	17,868	13,401	28,290	37,224	49,136	187,610	145,919	129,540
1978	5,377	34,056	44,810	59,150	59,150	216,882	200,750	53,772
1979	11,069	40,125	40,125	71,948	84,401	226,912	217,227	52,577
1980	4,285	28,567	17,141	58,563	61,420	74,276	148,551	41,423
1981	142,047	61,643	41,542	49,582	36,182	21,441	108,546	40,202
1982	78,064	109,290	112,412	67,135	31,225	29,665	42,155	7,806
1983	13,421	80,524	192,364	93,945	35,789	13,421	40,262	8,947
1984	6,107	58,019	94,663	195,432	42,751	27,483	18,322	3,053
1985	29,723	35,667	23,778	118,891	65,390	23,778	47,557	29,723
1986	11,831	153,802	31,549	35,493	110,422	7,887	3,944	0
1987	9,592	47,959	100,714	33,571	16,786	2,398	0	0
1988	35,138	55,218	128,004	45,178	30,119	10,040	0	0
1989	9,264	18,550	44,207	111,913	34,898	8,128	0	0

size of samples of clams collected for aging since 1982 (Table 9) and errors in age determination. It is also likely to be a result of changes in fishing mortality (F); changes in abundance (N) cannot be separated from changes in F when examining trends in harvest (C) [demonstrated by the Baranov relationship, $C=F\bar{N}$ (Deriso et al. 1989)]. Inferences about trends in the abundance of clams at Clam Gulch cannot be made by merely observing harvest over time without knowledge of annual fishing mortality rates.

Methods for age-structured analysis

Population parameters were estimated by the CAGEAN (Catch-at-AGE-ANalyis) model (Deriso et al. 1985, 1989). Widely used on freshwater and marine fish species, it has not been used on shellfish to the knowledge of this author. A nonlinear least squares procedure is used to minimize the sums of squares between the natural logarithm of observed catch and the natural logarithm of catch generated by the Baranov catch equation. Parameters include abundance estimates for the first year each cohort enters the analysis (year-class strength) and fishing mortalities for each age and year of the analysis. The model assumes that fishing mortality can be partitioned into a product of age-specific gear selectivity and full-recruitment fishing mortality. The separability assumption allows a biologically realistic fishing mortality factor to influence the population (as opposed to the constant fishing mortality assumptions of models in use before 1977) while reducing the number of parameters to be estimated. Selectivity values are estimated from the model or can be supplied by the user. Natural mortality, which can vary by age, must be supplied by the user. Auxiliary data such as spawner-recruit and effort information should be incorporated with catch data to estimate abundance because catch-at-age data alone are insufficient to generate reliable parameters (Deriso et al. 1985). The bootstrap technique (Efron 1982) is used to generate a mean and standard deviation of estimated parameters across bootstrap replications. The difference between the bootstrap mean and the original estimate is an estimate of bias; the bootstrap standard deviation is an estimate of the standard error of the original parameter estimate (Efron 1982).

The CAGEAN model generates the starting population parameters. Selectivity is assumed to be 1 for ages 7 to 11+. Natural mortality was obtained using the Alverson-Carney procedure (Alverson and Carney 1975), which sets M based on maximum age and von Bertalanffy growth parameter *k*. The von Bertalanffy model is

$$L_t = L_\infty(1-e^{k(t-t_0)})$$

where the change in length with time (L_t) is a function of asymptotic size (L_∞), a growth parameter (k) and initial age (t_0). The parameters were estimated using nonlinear least squares in the program LVB (Dr. Terrance J. Quinn, II, JCFOS, Juneau, Alaska, pers. comm). The estimate of the parameters was obtained from age-length data collected from Clam Gulch in July, 1984. The estimate of k was 0.234$\pm$ 0.0.034 (Quinn and Jones 1989). The Alverson-Carney model is

$$M = \frac{3k}{e^{t^*k}-1}$$

where k is the growth parameter from the previous equation and

$$t^* \approx \frac{t_m}{4}.$$

The parameter t_m is maximum age, which is about 12 for Clam Gulch clams. The best estimate of natural mortality from Quinn and Jones (1989) was 0.125.

Catch-age analysis is then performed using the starting values of abundance, selectivity and fishing mortality parameters from the model with auxiliary fishing mortality values derived from survey data (Deriso et al. 1989). Introduction of this "auxiliary" fishing mortality was possible because fishing effort is assumed to be proportional to fishing mortality (Deriso et al. 1989). Survey estimates of exploitation rates were converted to fishing mortality (F) by solving the Baranov catch equation for fishing mortality using abundance estimates from the survey (6.012 million in 1988, 3.102 million in 1989), producing auxiliary F's of 0.05 in 1988 and 0.08 in 1989.

Results and discussion of age-structured analyses

The survey "λ" values control the influence of auxiliary information on parameter estimation. Since spawner-recruit relationships require several years of data not yet available for razor clams this option of the model was not used and subsequent discussion will be limited to the effort parameter. The survey λ is the ratio of the variance of the observed logarithm of catch to the variance of the observed logarithm of survey F. A high survey λ forces the output to conform to the observed F. Figure 15a demonstrates the effect of a range of λ values on the least squares estimates of total numerical abundance. The difference between the least squares estimate of abundance (Figure 15a) and the bootstrap mean of abundance (Figure 15b) is an estimate of bias. A λ of 1000 produces the highest standard errors of total numerical abundance (Figure 16). The bias is small compared to the standard error of the bootstrap estimates (Figure 16).

The divergence of the least squares and bootstrap estimates (Figures 15a to 15b) in the later years is characteristic of a forward projection of a cohort. It is a result of the model's sensitivity to auxiliary values of fishing mortality. Errors occur in fishing mortality values for older ages using a forward projection unless the terminal fishing mortality is close to the true fishing mortality (Megrey 1989). Therefore recent estimates of abundance are as accurate as the estimates of fishing mortality used to calculate them.

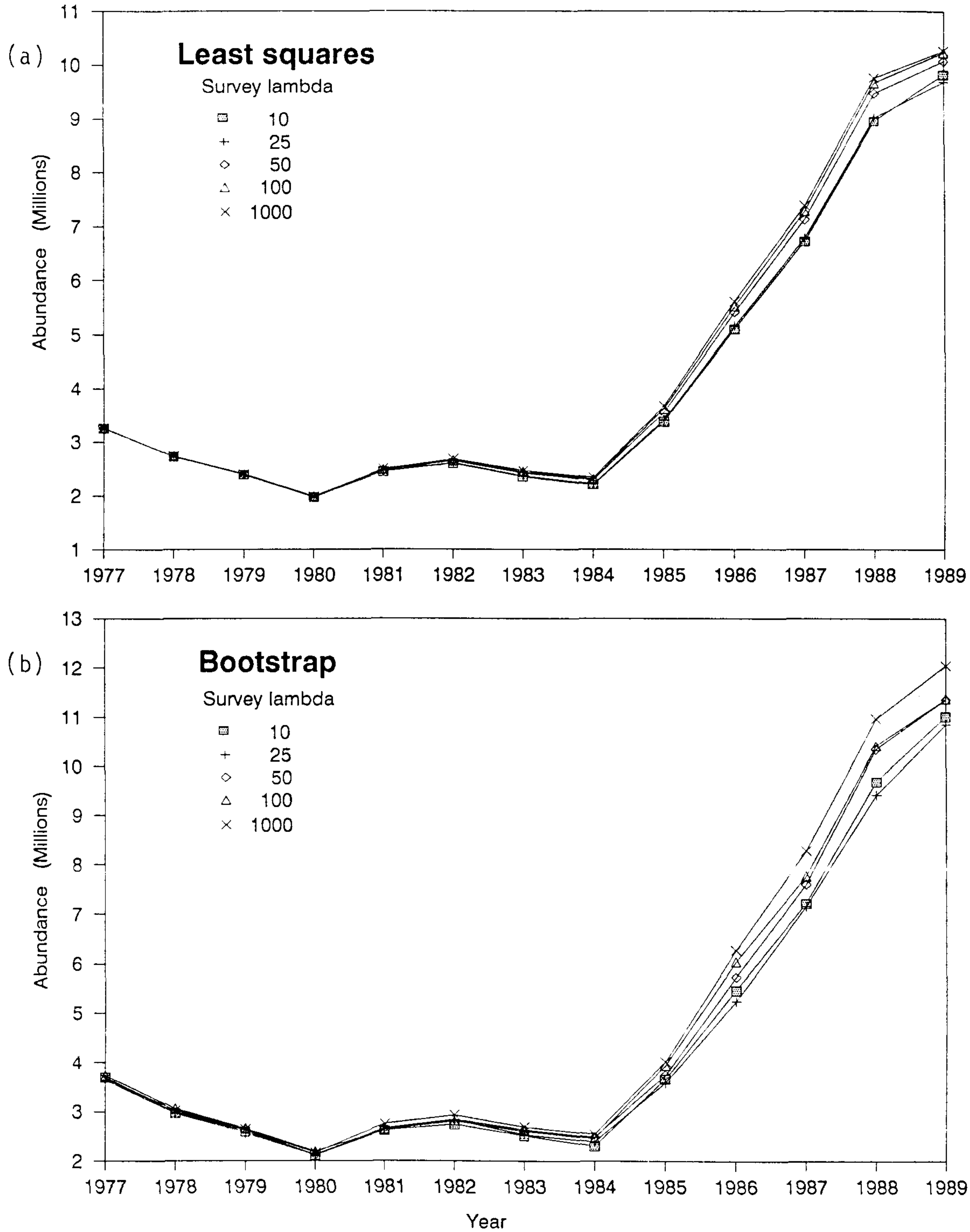


Figure 15. Total numerical abundance estimates from CAGEAN as a function of survey λ. (a) least squares estimate, (b) bootstrap means

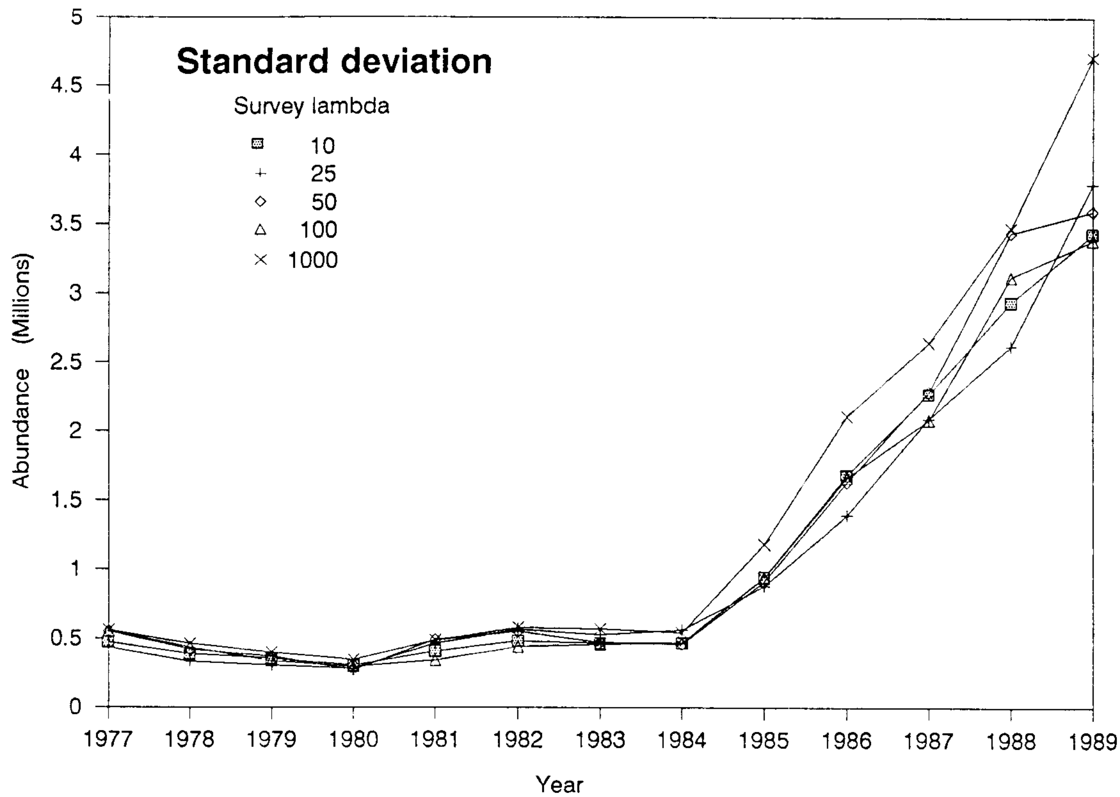


Figure 16. Bootstrap standard deviation from CAGEAN as a function of survey λ.

In order to choose a value of λ it is necessary to adjust total abundance, estimated by CAGEAN by selectivity estimates from the model to obtain the harvestable abundance estimates. This allows a comparison of model parameters with the survey, which estimates the abundance of harvestable clams. Parameter estimates with $\lambda = 50$ are chosen because the adjusted abundance falls between the survey estimates of abundance in 1988 (6.012 million clams) and 1989 (3.102 million clams) and are midway between the estimates predicted using other survey λ values (Figure 17).

Estimates of total abundance and adjusted abundance for the period of 1977 to 1989 are found in Table 11. Cohorts can be followed along the diagonals of the table or across Figures 18a, b, c. The 1968 year-class is 9 years old when it enters the fishery in 1977, the 1969 year-class is 8 years old when it enters the fishery in 1977, etc. (Figure 18a). The increase in abundance in the eleventh year of life is a result of the pooling of the older age-classes. The 1968 cohort appears to have been the strongest of these older age-classes. The 1977 year-class (Figure 18b) enters the fishery more than 950,000-strong. This large cohort is reported in Nelson (1982). The abundant 1978 year-class was not observed by Nelson (1982); its magnitude could be a result of errors in aging the progeny of 1977. The abundance of the 1981 through 1984 year-classes meets or surpasses that of 1977 (Figure 18c). Year-class strength at age of entry into the fishery is strong for the 1977 and 1981 through 1984 year-classes (Figure 19).

Catch-age analysis does not provide precise information to a manager about recent stock abundance or the parameters governing abundance without exact knowledge of current mortality. As better information from surveys becomes available abundance estimates will become more precise. Valuable information can be extracted from the results of this analysis. Estimates of total abundance prior to 1985 are similar over λ values (Figure 15a). The magnitude of more recent estimates is greater than in any other year of the analysis, albeit more variable, suggesting that there has been

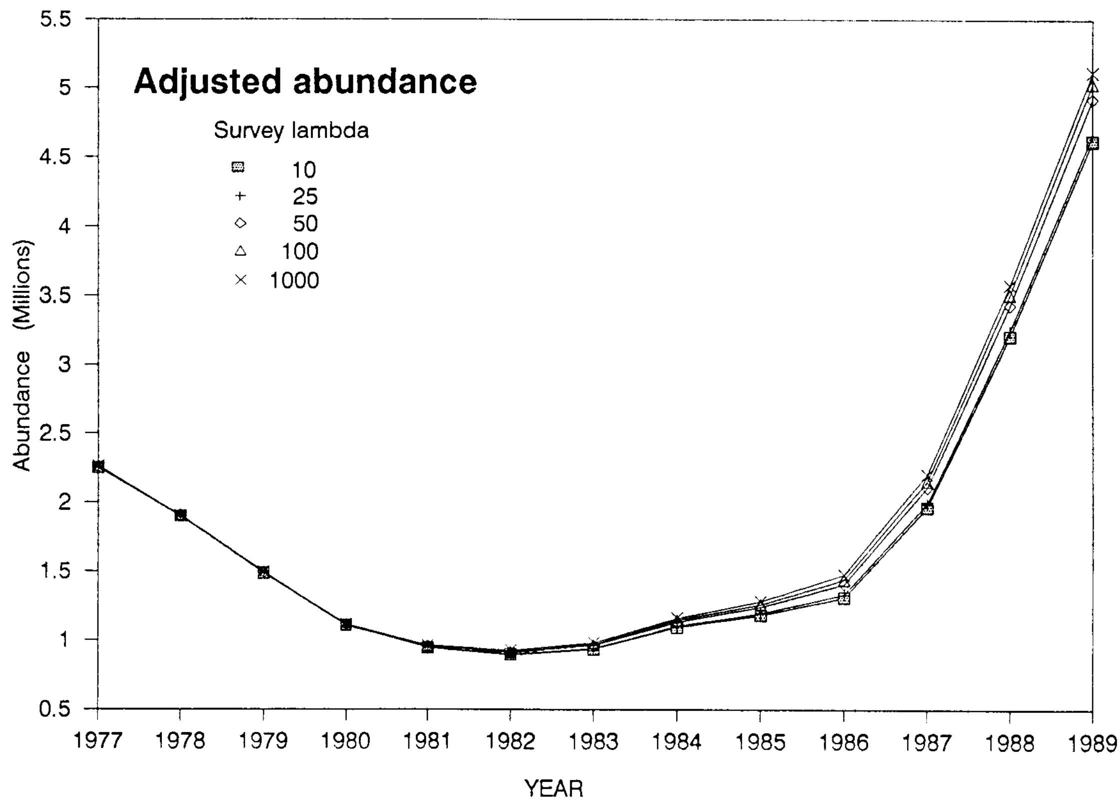


Figure 17. Total numerical abundance from CAGEAN adjusted by selectivity values from CAGEAN.

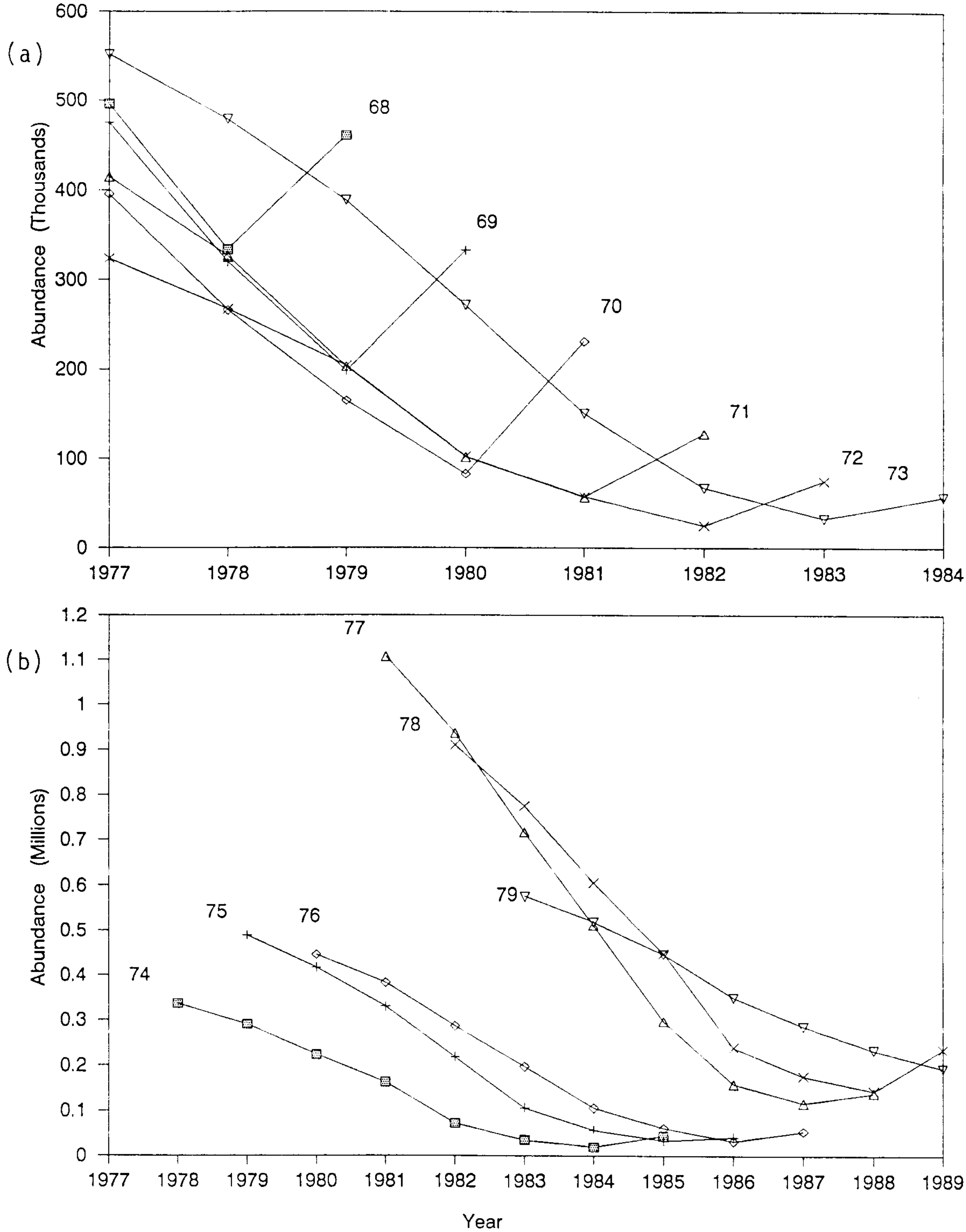
Table 11. Estimated total numerical abundance and adjusted numerical abundance of clams at Clam Gulch from CAGEAN (λ=50, number of bootstraps=100).

Total numerical abundance

Year	Age 4	5	6	7	8	9	10	11+
1977	551,686	323,610	414,481	395,626	475,225	495,883	240,497	366,604
1978	336,285	478,838	267,519	326,759	266,184	319,740	333,639	408,469
1979	489,427	290,439	388,210	203,931	202,783	165,191	198,428	460,545
1980	446,432	417,356	223,970	271,435	102,809	102,231	83,279	332,213
1981	1,107,220	383,000	329,584	163,159	151,033	57,206	56,884	231,190
1982	910,333	936,877	286,472	218,620	72,468	67,083	25,408	127,951
1983	481,310	774,692	716,668	197,533	106,589	35,332	32,706	74,770
1984	518,707	411,734	604,875	511,966	104,860	56,582	18,756	57,054
1985	1,896,076	446,111	328,331	448,124	296,641	60,758	32,785	43,925
1986	2,733,125	1,622,678	348,905	235,228	239,544	158,569	32,478	41,005
1987	2,572,376	2,384,991	1,370,032	285,267	172,758	175,928	116,458	53,968
1988	3,307,058	2,259,220	2,065,305	1,170,205	232,734	140,944	143,530	139,042
1989	1,907,500	2,907,371	1,964,105	1,776,091	970,429	193,002	116,882	234,331

Adjusted numerical abundance

Year	Age 4	5	6	7	8	9	10	11+
1977	33,793	77,957	172,352	395,626	475,225	495,883	240,497	366,604
1978	20,599	115,351	111,242	326,759	266,184	319,740	333,639	408,469
1979	29,979	69,966	161,428	203,931	202,783	165,191	198,428	460,545
1980	27,346	100,540	93,133	271,435	102,809	102,231	83,279	332,213
1981	67,822	92,264	137,050	163,159	151,033	57,206	56,884	231,190
1982	55,761	225,692	119,123	218,620	72,468	67,083	25,408	127,951
1983	29,482	186,622	298,010	197,533	106,589	35,332	32,706	74,770
1984	31,773	99,186	251,523	511,966	104,860	56,582	18,756	57,054
1985	116,142	107,467	136,529	448,124	296,641	60,758	32,785	43,925
1986	167,415	390,900	145,084	235,228	239,544	158,569	32,478	41,005
1987	157,568	574,539	569,696	285,267	172,758	175,928	116,458	53,968
1988	202,570	544,241	858,810	1,170,205	232,734	140,944	143,530	139,042
1989	116,842	700,380	816,728	1,776,091	970,429	193,002	116,882	234,331



Figures 18a and b. Estimated total abundance by year class from CAGEAN (λ=50, bootstraps=100).

(c)

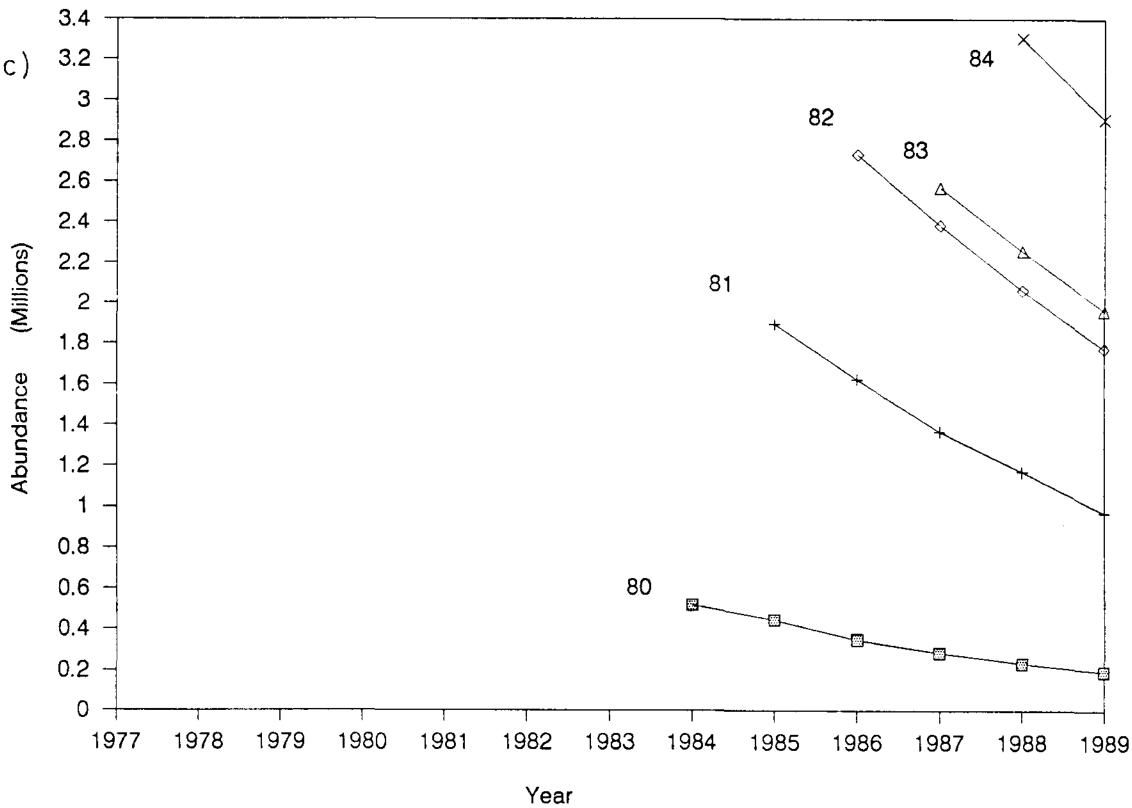


Figure 18c. Estimated total abundance by year class from CAGEAN (λ=50, bootstraps=100).

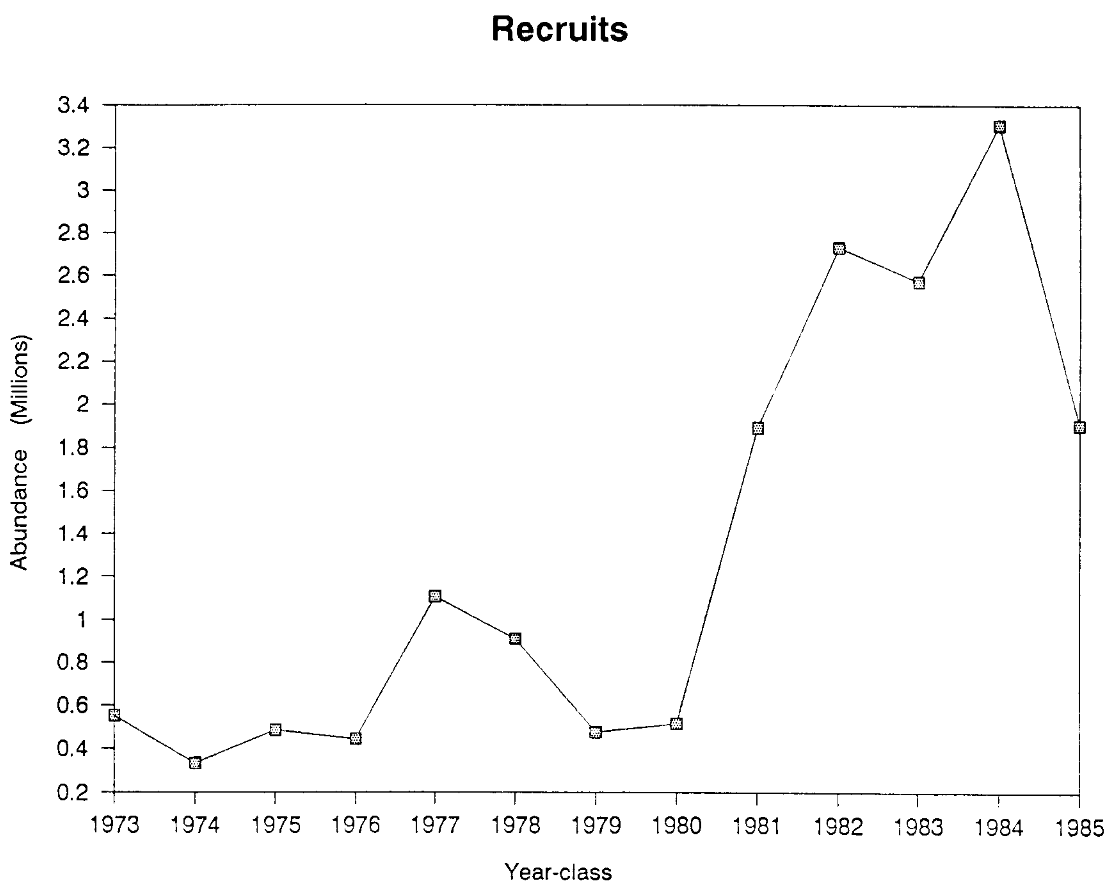


Figure 19. Estimated total abundance of recruits into the harvest from CAGEAN.

excellent recruitment since 1985.

Estimated age specific fishing mortality and survival rates from Clam Gulch are variable (Table 12) in comparison to estimates from other localities. Hirschhorn (1962) measured average fishing mortalities of 0.65 on Oregon beaches for clams >88 mm (1+ years). Survival rates on Cordova beaches for clams aged 3+ were estimated at 0.4 (Nickerson 1975). The age of full selectivity of razor clams at Clam Gulch may be less than 7, however samples for aging have not been collected from the harvest for verification.

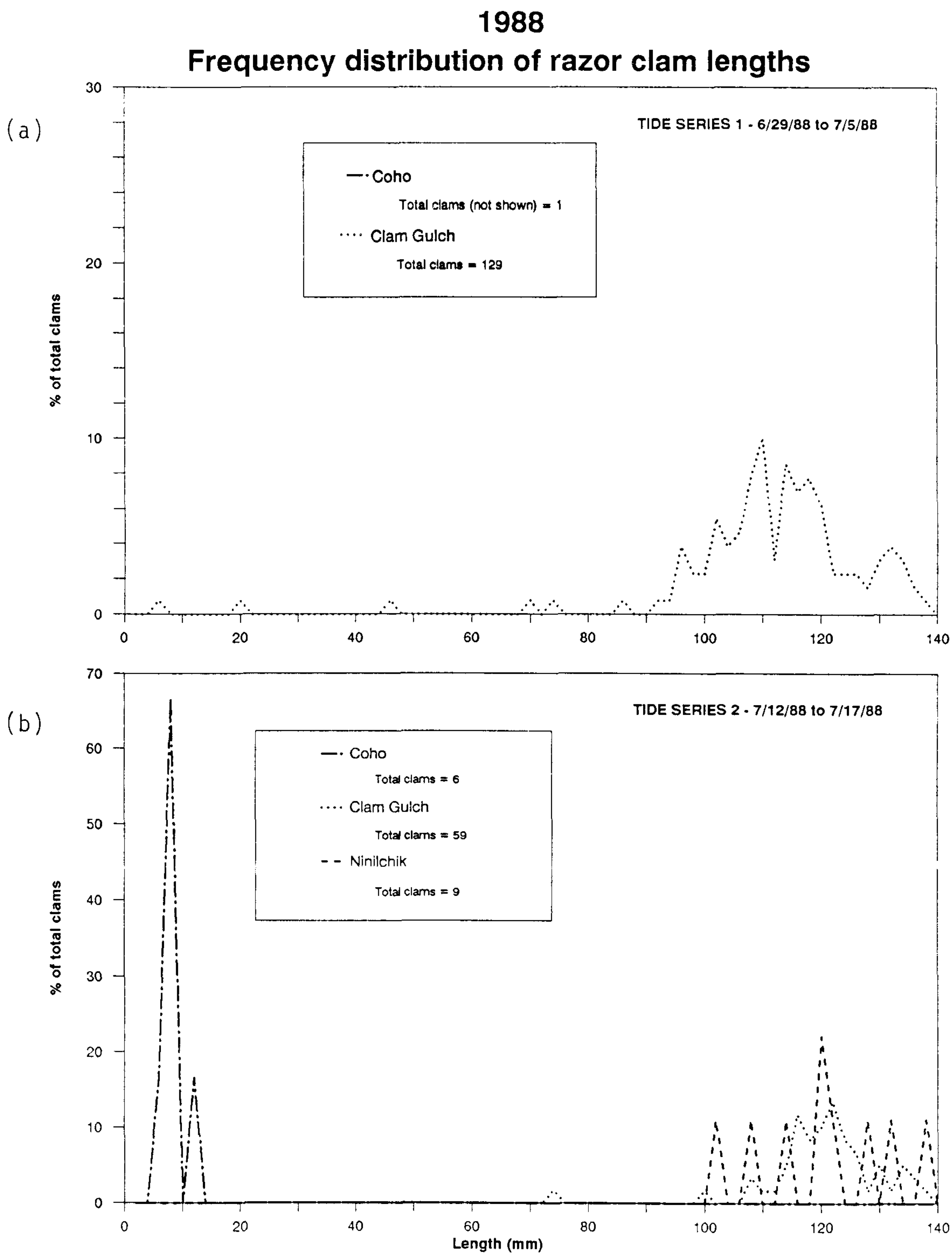
Despite the decline in the harvest at Clam Gulch in recent years (Table 10), both adjusted abundance and total abundance (Table 11) increase. This result can be explained by the confounding of fishing mortality and abundance in explaining catch, as in the Baranov relationship, $C=F\bar{N}$. At Clam Gulch, the CAGEAN analysis indicates that fishing mortality (Table 12) has decreased more than the increase in abundance to explain the decline in catch. Use of the survey abundance as auxiliary information allows the trends in abundance and fishing mortality to be resolved in the analysis of catch-age data.

Length frequency data

In 1988, all clams were collected to be measured for length and to be aged. In 1989, all clams were measured for length in the field and a subset was aged. Figures 20a-d and 21a-h depict the length frequencies in each tide series of each year graphically. The frequency of clam lengths are recorded in the figures as the number of clams in each 2 mm length category divided by the total number of clams measured for each tide series. Length frequencies are reported in percentages for greater ease of comparison between areas and sample periods where there were large differences in the numbers of clams measured. The number of clams measured for lengths is included on the figures.

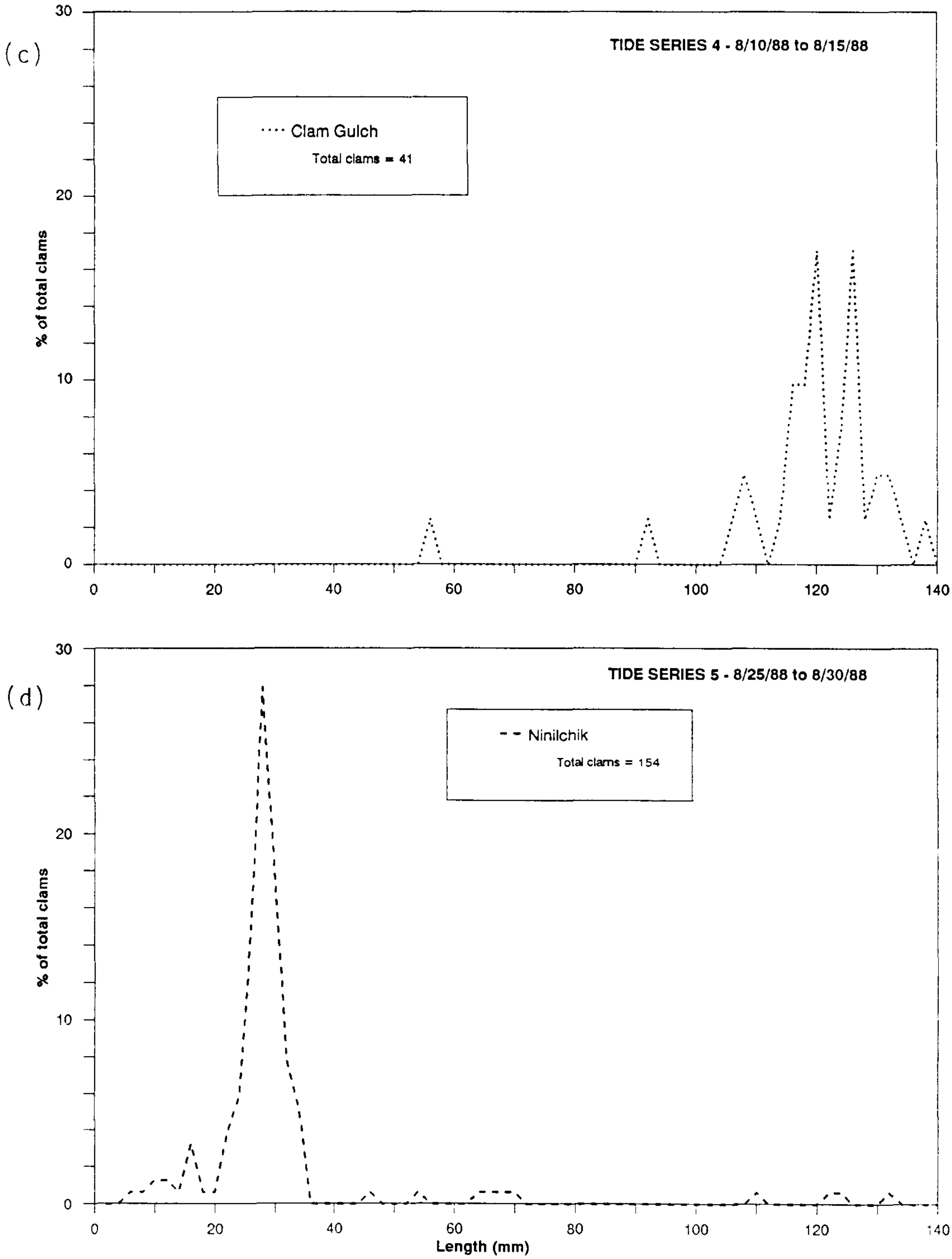
Table 12. Age specific selectivity, fishing mortality and survival values from CAGEAN.

	Age							
	4	5	6	7	8	9	10	11+
	Age specific selectivity							
	0.07	0.25	0.42	1.00	1.00	1.00	1.00	1.00
Year	**Fishing mortality**							
1977	0.02	0.07	0.11	0.27	0.27	0.27	0.27	0.27
1978	0.02	0.09	0.15	0.35	0.35	0.35	0.35	0.35
1979	0.04	0.14	0.23	0.56	0.56	0.56	0.56	0.56
1980	0.03	0.12	0.20	0.47	0.47	0.47	0.47	0.47
1981	0.05	0.18	0.30	0.71	0.71	0.71	0.71	0.71
1982	0.04	0.16	0.27	0.64	0.64	0.64	0.64	0.64
1983	0.04	0.15	0.24	0.58	0.58	0.58	0.58	0.58
1984	0.04	0.13	0.22	0.53	0.53	0.53	0.53	0.53
1985	0.05	0.19	0.32	0.76	0.76	0.76	0.76	0.76
1986	0.02	0.08	0.13	0.32	0.32	0.32	0.32	0.32
1987	0.01	0.04	0.06	0.14	0.14	0.14	0.14	0.14
1988	0.01	0.02	0.04	0.08	0.08	0.08	0.08	0.08
1989	0.02	0.06	0.11	0.26	0.26	0.26	0.26	0.26
	Age specific survival							
1977	0.86	0.81	0.76	0.61	0.61	0.61	0.61	0.61
1978	0.85	0.79	0.73	0.53	0.53	0.53	0.53	0.53
1979	0.84	0.73	0.64	0.32	0.32	0.32	0.32	0.32
1980	0.84	0.76	0.68	0.41	0.41	0.41	0.41	0.41
1981	0.83	0.70	0.58	0.17	0.17	0.17	0.17	0.17
1982	0.83	0.71	0.61	0.24	0.24	0.24	0.24	0.24
1983	0.83	0.73	0.63	0.30	0.30	0.30	0.30	0.30
1984	0.84	0.74	0.65	0.34	0.34	0.34	0.34	0.34
1985	0.82	0.68	0.56	0.12	0.12	0.12	0.12	0.12
1986	0.85	0.80	0.74	0.56	0.56	0.56	0.56	0.56
1987	0.87	0.84	0.82	0.73	0.73	0.73	0.73	0.73
1988	0.87	0.85	0.84	0.79	0.79	0.79	0.79	0.79
1989	0.86	0.81	0.77	0.62	0.62	0.62	0.62	0.62

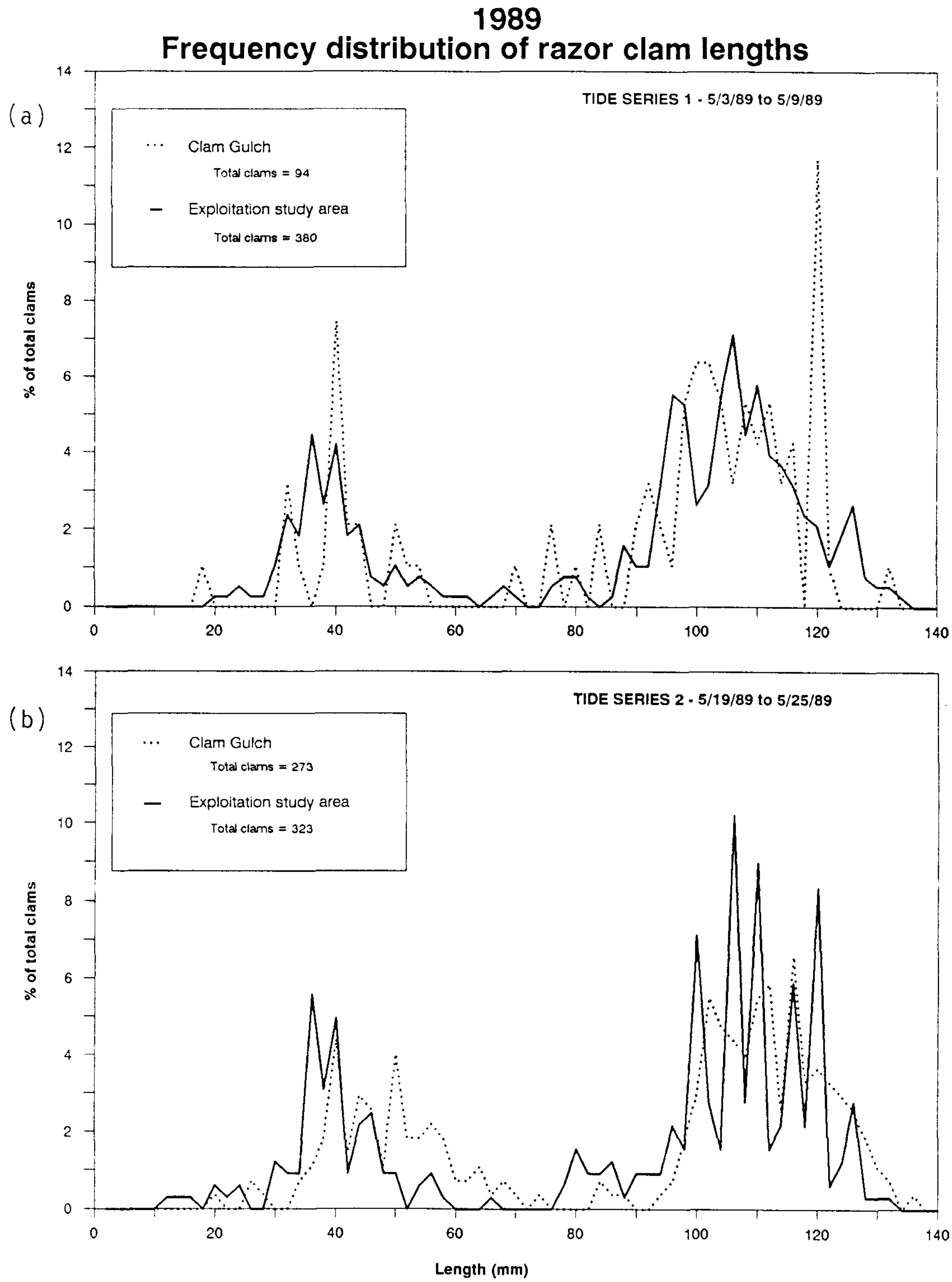


Figures 20a-d. Frequency distribution of clam lengths, 1988.

1988 cont.



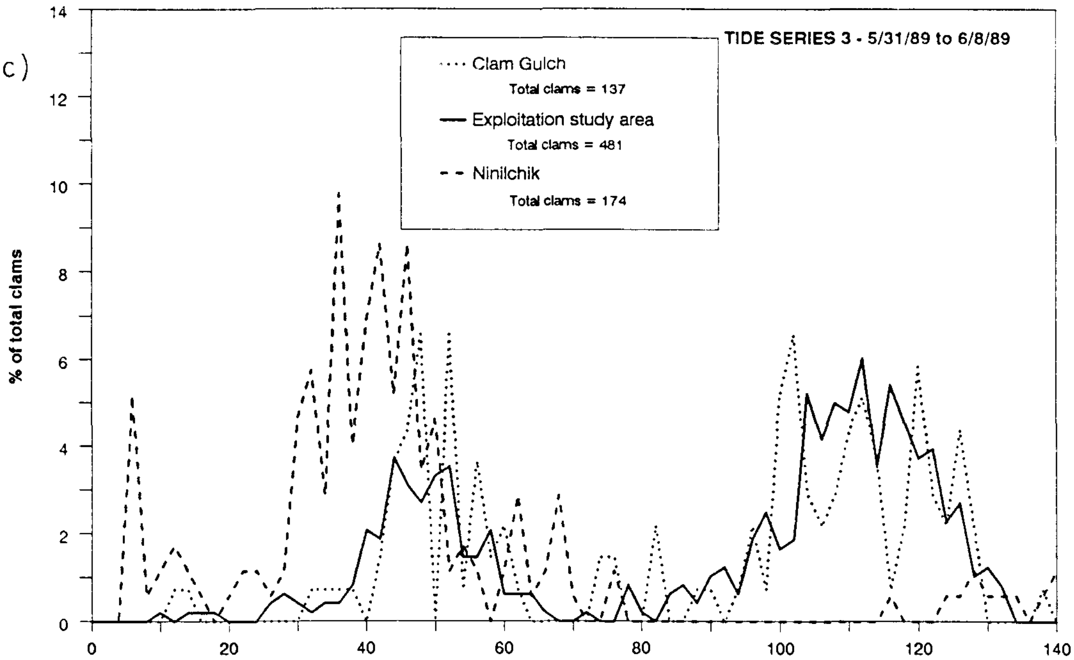
Figures 20a-d, continued.



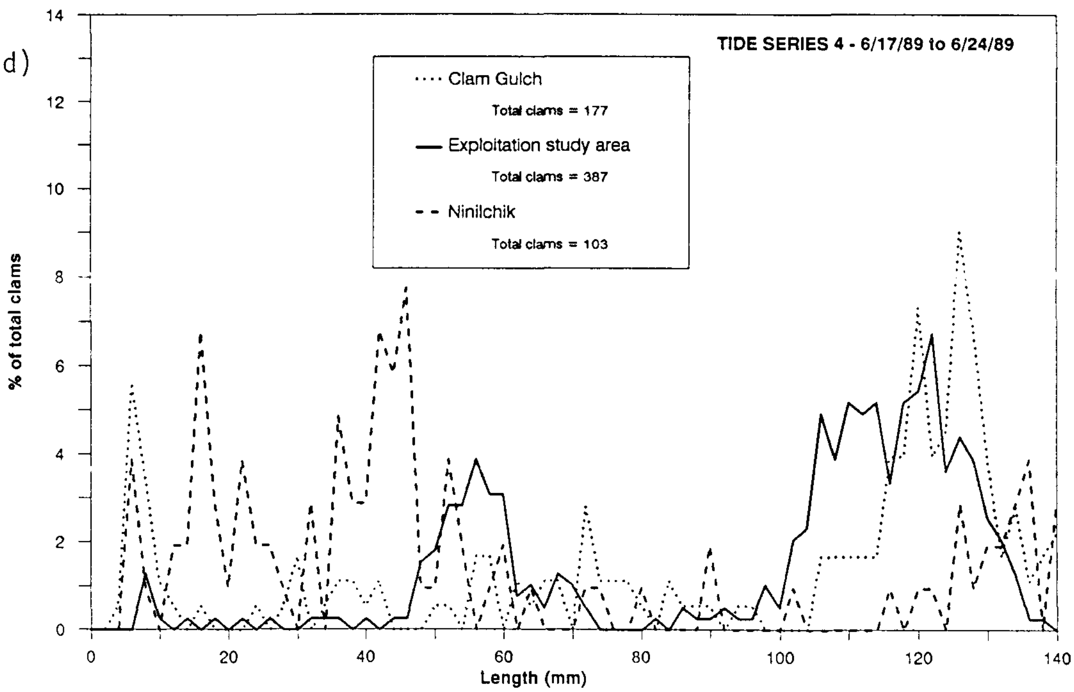
Figures 21a-h. Frequency distributions of clam lengths, 1989.

1989 cont.

(c)



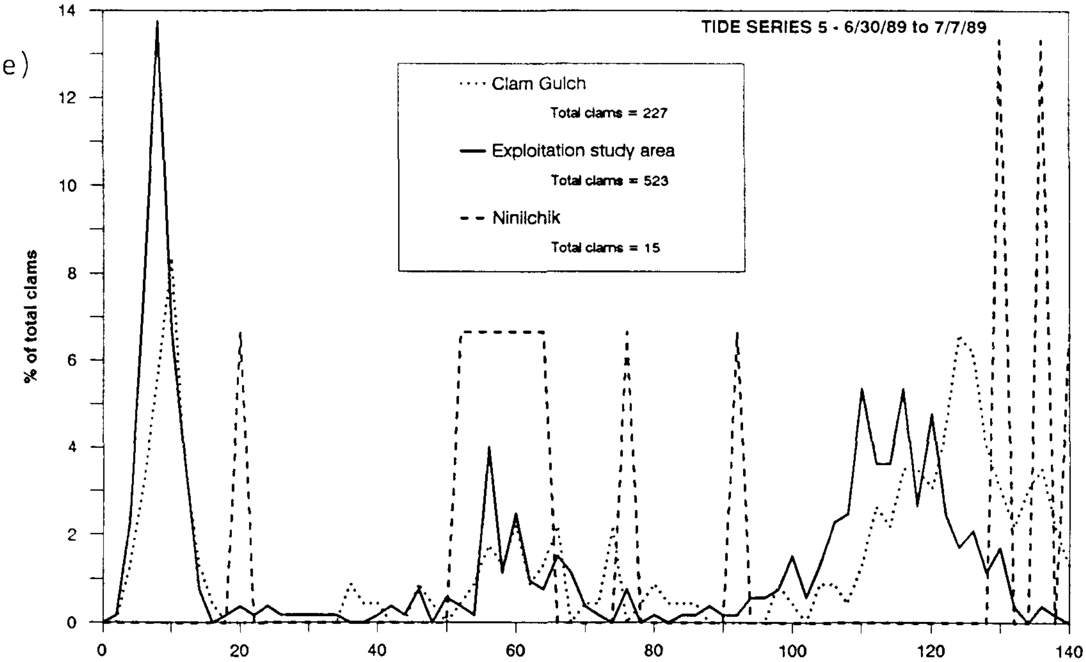
(d)



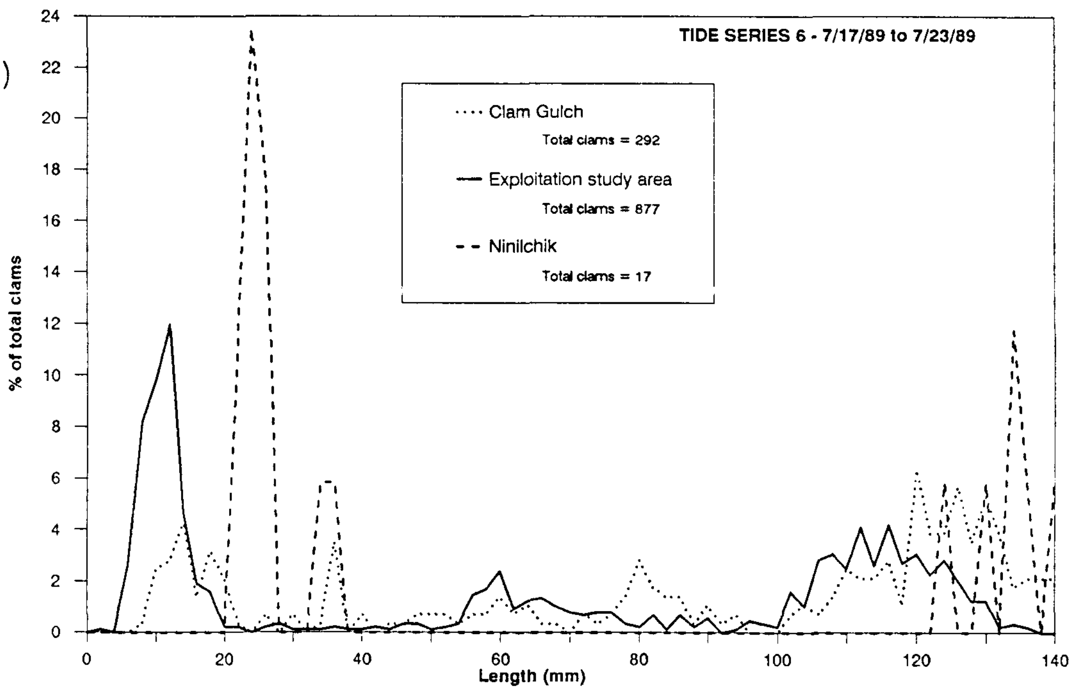
Figures 21a-h, continued.

1989 cont.

(e)



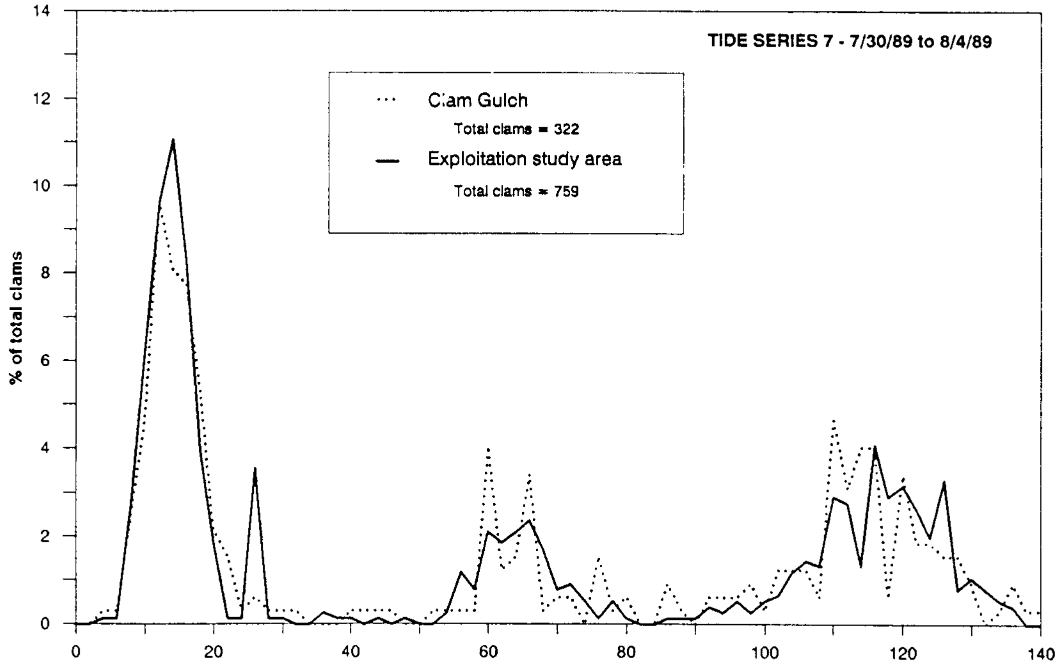
(f)



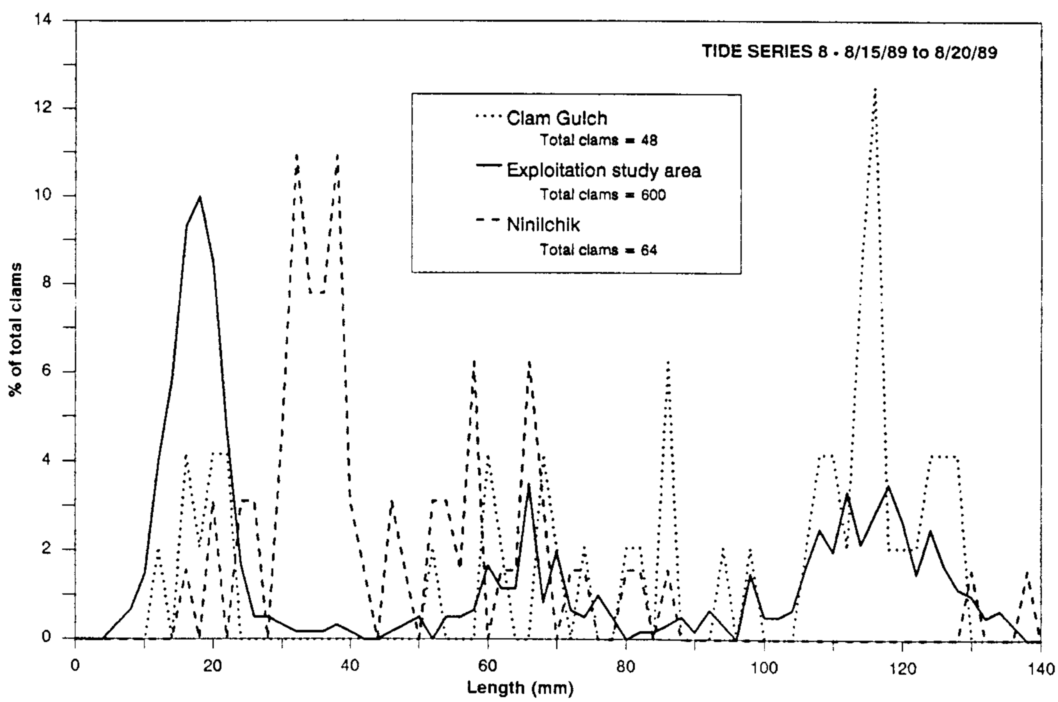
Figures 21a-h, continued.

1989 cont.

(g)



(h)



Figures 21a-h, continued.

Data loss and many samples that contained no clams make trends difficult to trace in 1988. Many shells were broken before they could be processed. Tide series three in 1988 is absent because of the accidental destruction of the shells from that period.

Few small clams were seen on the beaches in 1988. However, at Ninilchik, during the final tide series in August over 30% of the clams sampled were less than 30 mm (Figure 20d). Large clams appear to be abundant at Clam Gulch throughout the summer.

In contrast to 1988, a large influx of clams less than 10 mm in length is evident in 1989 starting in early June at Ninilchik (Figure 21c) and mid-June at Clam Gulch (Figure 21d). The numbers of these small clams increased in July and persisted throughout the summer. The June arrival of these small clams indicates that they are from the previous years set. These clams overwintered at an unusually small size. Another peak of 4 mm clams is visible during the latter part of July which is evident for the duration of the sampling. Many small clams were found in final tide series which had delicate shells; many of the small clams found earlier in the summer had thicker shells. The 4 mm clams could signal the arrival of the progeny of the 1989 reproductive effort.

Large numbers of clams approximately 35-45 mm and 90-120 mm in length were found at Clam Gulch and the exploitation study area throughout the summer suggesting that strong year classes might be represented at age 2 (1987 year-class) and ages 5-8 (1980-1984 year-classes), supporting the catch-age analysis.

The shapes of the peaks of the prominent size classes vary greatly between sampling periods but the sizes at which the peaks occur increase during the summer. The 8 mm clams double their size to almost 20 mm by the end of the summer. The net increase in growth for the 40 mm clams is approximately 25 mm from the start of sampling in May to its conclusion in

August. Nelson (1982) reports similar sizes and growth rates for clams in their third summer. He also notes this is the time of greatest absolute growth in the life cycle of the razor clam. The largest clams in our samples grew approximately 10 mm during the summer. This is consistent with the slow growth rates reported for larger clams by Nelson (1982) and other investigators (Weymouth et al. 1925).

Prominent peaks of clams of certain sizes are consistent between Clam Gulch and the exploitation study area indicating that we are detecting fluctuations in clam stocks, not variability due to sampling strategy alone.

Perhaps length frequencies can be used to supplement age-structured analysis. Length frequency analysis may be helpful in detecting the presence of the younger age classes. Growth is rapid and size classes may be distinguished up to the 5th year of life (Nelson 1982). Unfortunately, limiting the catch-at-age analysis to clams of harvestable size precluded the use of the length frequency data to validate the age frequencies of younger clams. The difficulty in decomposing the length frequencies of larger clams into age-classes made age validation of large clams infeasible as well. Inferring age distribution from length frequency is problematic due to the strong growth of clams over the sampling period. However, estimation of growth rates may be possible from time series of length frequency data.

Razor clam tacos

Fresh cleaned razor clams (4-5 per person)
1/2 c corn meal
1/2 c flour
1 egg
2 diced or grated garlic cloves per medium skillet of clams
corn or flour tortillas (2 per person)
grated cheddar cheese
butter
oil

Condiments: *tartar sauce, picante sauce, sliced onions, tomatoes, cabbage or lettuce, mushrooms, green pepper, avocado*

Mix the corn meal and flour in equal parts. Stir the clams in the beaten egg, drain and roll them in the flour mixture. Heat the garlic in butter over low heat. Increase the heat and add several clams. Fry the clams quickly until they brown (about 1 minute per side). **Do not overcook them!** *Set the cooked clams on paper to drain. Add oil to another skillet. Place a tortilla in the skillet and flip it immediately. Sprinkle the grated cheese over the tortilla, allowing it to melt and continue heating until the tortilla is lightly crisp. Add 2 or 3 clams and the condiments of your choice to the tortilla, roll and serve it. Place a new tortilla on the frying pan and repeat.*

CHAPTER 4

THE ROLE OF THE ENVIRONMENT IN DISTRIBUTION

Environmental factors affect clams in all stages of development at all times while harvesters affect mostly larger clams. Over-harvesting is possible, however, and has occurred on beaches in Oregon, Washington and British Columbia as well as Alaskan beaches near Cordova. The population of razor clams on the Clatsop beaches of Oregon fluctuates independently of harvest intensity (Nelson 1982). Environmental factors may have a greater influence on razor clam abundance than the number of adult spawning clams (Nelson 1982).

Environmental factors such as air and water temperature, salinity, wind direction and velocity, water currents, beach slope and attitude, substrate composition, food availability and the quantity of razor clams competing for resources regulate razor clam population size and distribution on Eastside beaches to a greater extent than harvest pressure (Nelson 1982). Substrate composition was chosen as the principal focus of this study. Salinity, water temperature, precipitation, cloud cover, wind speed and direction, air temperature, and relative humidity were measured as time permitted.

Substrate

Substrate composition is thought to have an important influence on clam abundance and size (Nelson 1982, Nickerson 1975). Substrate collection and grain size analysis were undertaken during this study to test the null hypothesis that substrate is unimportant in explaining razor clam density. In addition, the hypothesis that substrate stratification could be detected within the cores was tested to see if shallower cores could be collected for prediction of clam densities.

Methods

A corer was constructed out of galvanized pipe with a reinforced top (Figure 22). This was pounded into the beach at each beach level where samples for clam density were collected to a maximum depth of 46 cm. During 1988 only, cores were subdivided. In 1989 the same procedure was followed but cores were used in their entirety.

Single cores were transferred to a clear graduated plexiglas tube and subdivided into six inch sections measured from the top of the tube. The subcores were transferred to plastic bags and labeled for analysis of grain size composition.

Each six inch subcore was mixed by hand and subsampled by scooping out a variable amount of the substrate - a smaller amount was needed from the more homogeneous samples (Dr. Sathy Naidu, University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, Alaska, pers. comm.). The subsample was weighed in a beaker and dried at 110° C then cooled in a desiccating chamber and weighed again. The subsample was soaked in sodium hexametaphosphate to deflocculate the substrate then washed on a 63 micrometer sieve, dried and weighed. The sieve contents were then shaken through a series of graded sieves using a mechanical shaker and the contents of each sieve weighed to determine the percent of the different particle sizes composing the original subcore. The sieve mesh sizes appropriate for analysis of marine sediments and their effect on benthic organisms were chosen according to the recommendations of Buchanan and Kain (1964).

Results

In the following analyses, the contents of each core were multiplied by the number of samples collected at the corresponding beach level.

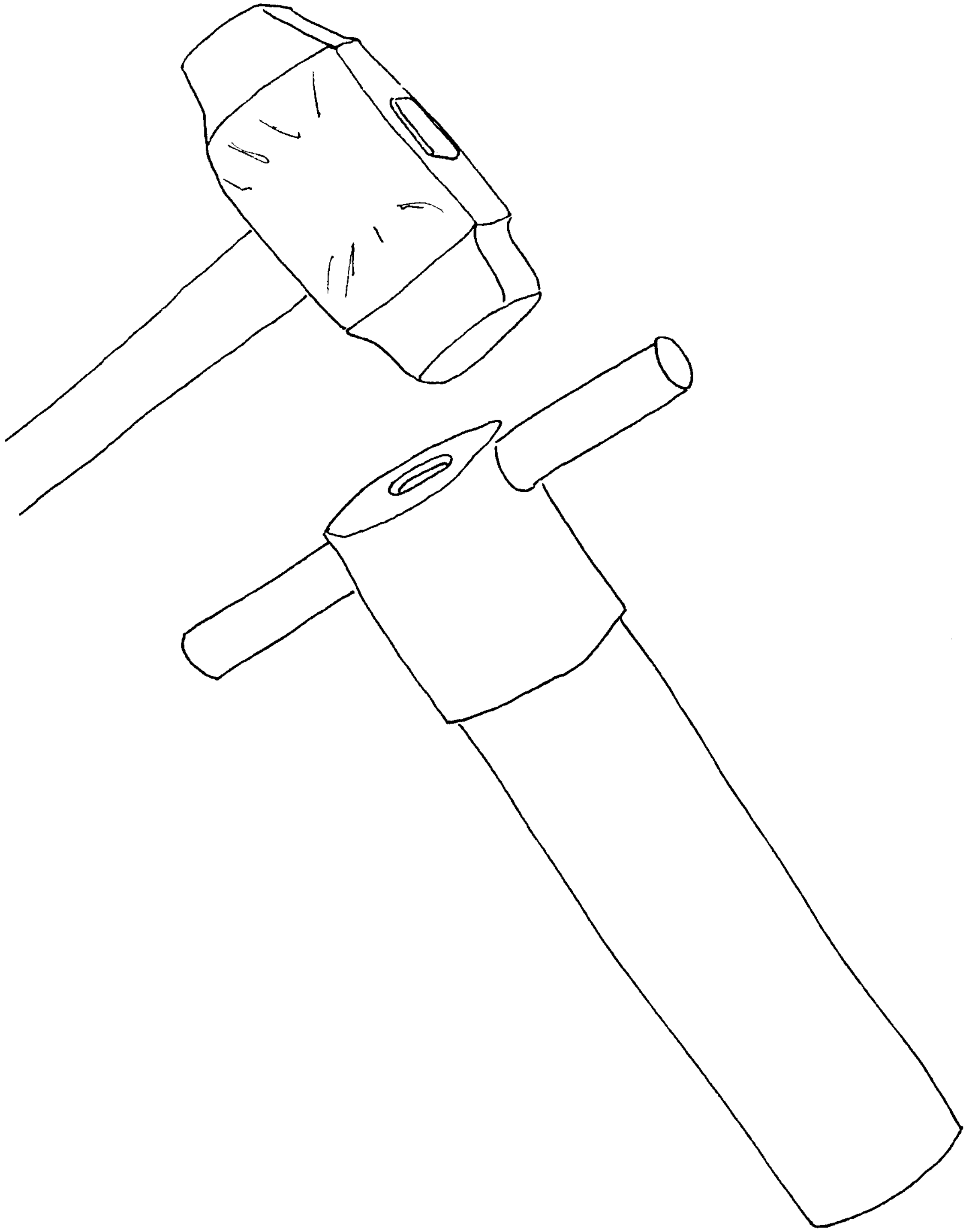


Figure 22. Core sampler.

Subcore analysis

The sieving of top, middle, and bottom subcores produced data on the percentages in 8 grain size categories (Table 13). Sample sizes in the analysis were small. Many sections of cores were unusable because labels identifying the subcores disintegrated or became unreadable.

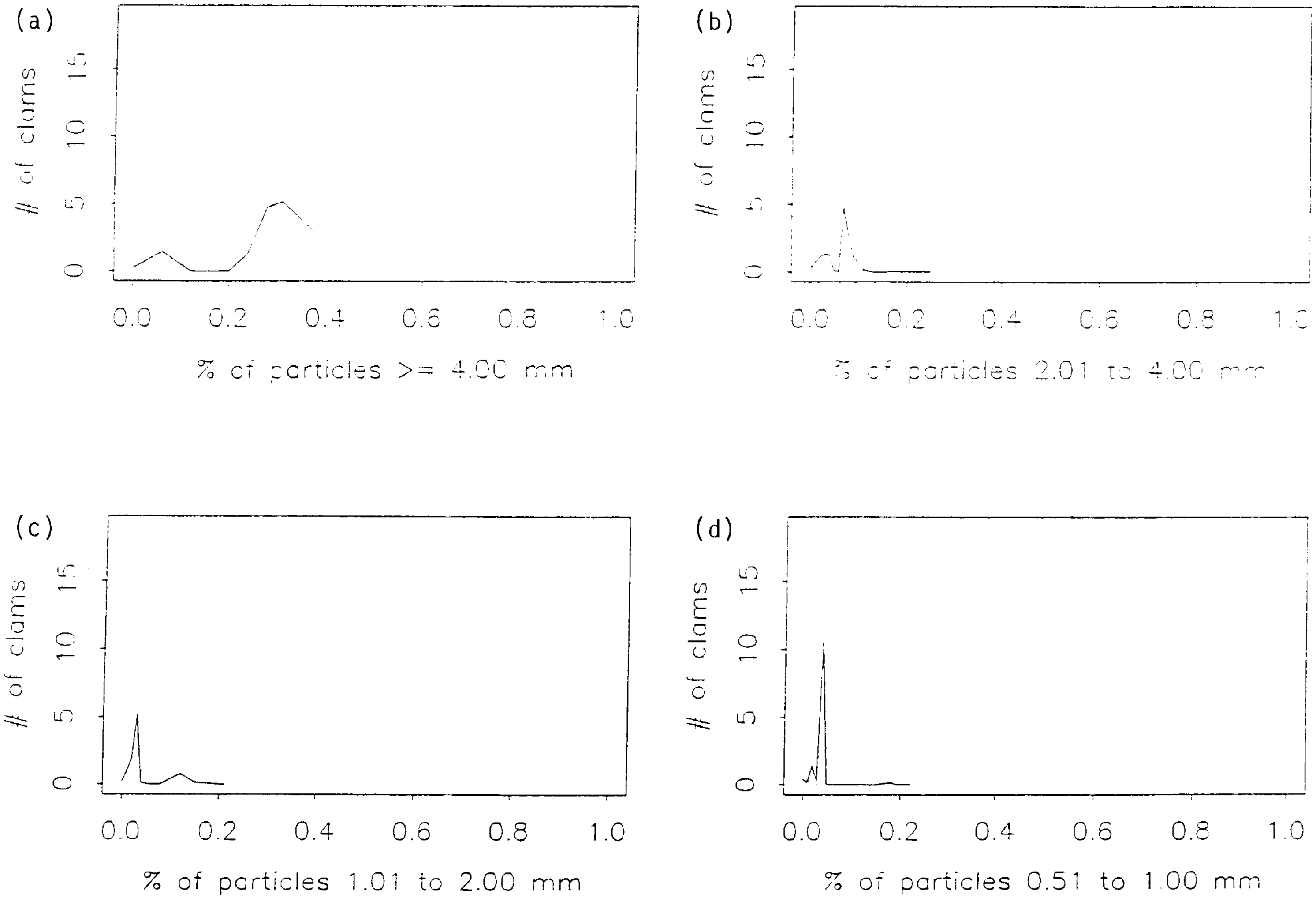
A multivariate analysis of variance was conducted on all subcores to determine if there was a significant difference between them. For this analysis arcsine square root transformations of the percentages of the grain sizes in the cores were used to normalize the data. P-values are all larger than 0.1 demonstrating that differences in means between top, middle and bottom sections of the cores are insignificant (Table 13) meaning subdivision of the cores is unnecessary. Percentages were therefore averaged across top, middle, and bottom subcores in subsequent analysis for 1988 and cores were not subdivided in 1989.

Grain size and clam density

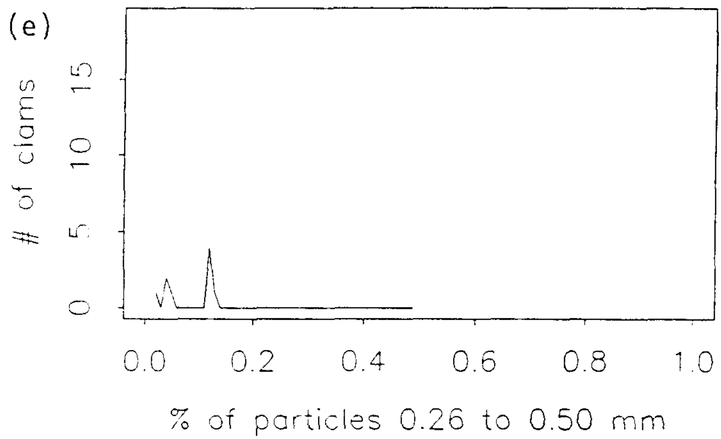
Classical exploratory data analysis techniques were employed first to examine the relationship of razor clam density substrate grain size. The statistical package "S" (Becker and Chambers 1984) was used to generate Lowess curves (Chambers et al. 1983) on plots of clam densities versus the percentages of the different grain sizes in the cores. The relationships for the grain size categories for the two years are found in Figures 23a-h, and 24a-h. Often no clams were found in samples for which substrate composition was determined. As a consequence, the Lowess curves are more conservative than would be expected from a visual inspection of the graphs. Clam densities appear to peak when a core contains between zero and 10 percent of most of the grain size categories. An exception is the pebble category (>4.00 mm); a peak occurs when 30 percent of that category is present in the cores (Figures 23a and 24a). Two prominent peaks in clam density correspond to the amount of substrate that is fine sand (0.126 to 0.25 mm): one at 20 percent and one between 60 and 80 percent (Figures 23f and 24f). A peak is seen when 13 percent is very fine

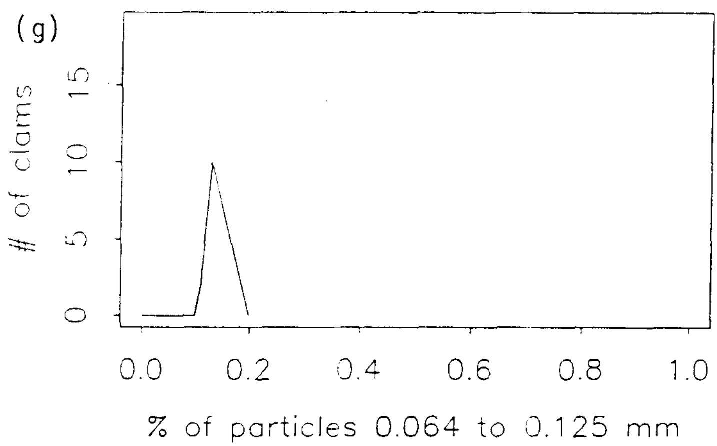
Table 13. Results of ANOVA to test the difference in grain size content of subcores.

	Size range (mm)							
	≥4.01	2.01-4.00	1.01-2.00	0.51-1.00	0.26-0.50	0.126-0.25	0.064-0.126	≤0.063
df								
Between	2	2	2	2	2	2	2	2
Within	106	106	106	106	106	106	106	106
SS								
Between	0.006	0.038	0.032	0.028	0.055	0.067	0.045	0.094
Within	4.533	1.985	1.841	2.194	3.376	9.873	1.421	3.818
MS								
Between	0.003	0.019	0.016	0.014	0.028	0.033	0.022	0.047
Within	0.043	0.019	0.017	0.021	0.032	0.093	0.013	0.036
F	0.068	1.024	0.913	0.666	0.864	0.368	1.676	1.310
P-value	0.934	0.363	0.405	0.516	0.424	0.700	0.919	0.274

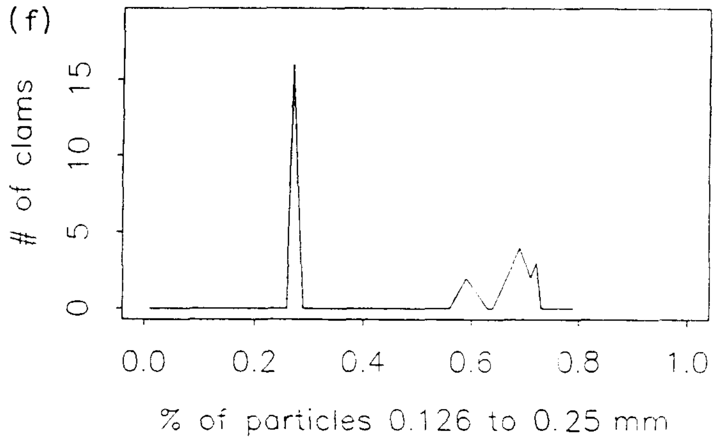


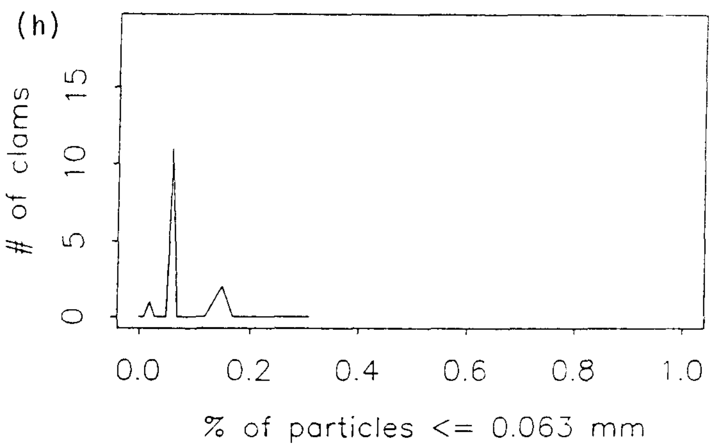
Figures 23a-h. Lowess analysis of grain size distribution in substrate cores, 1988.

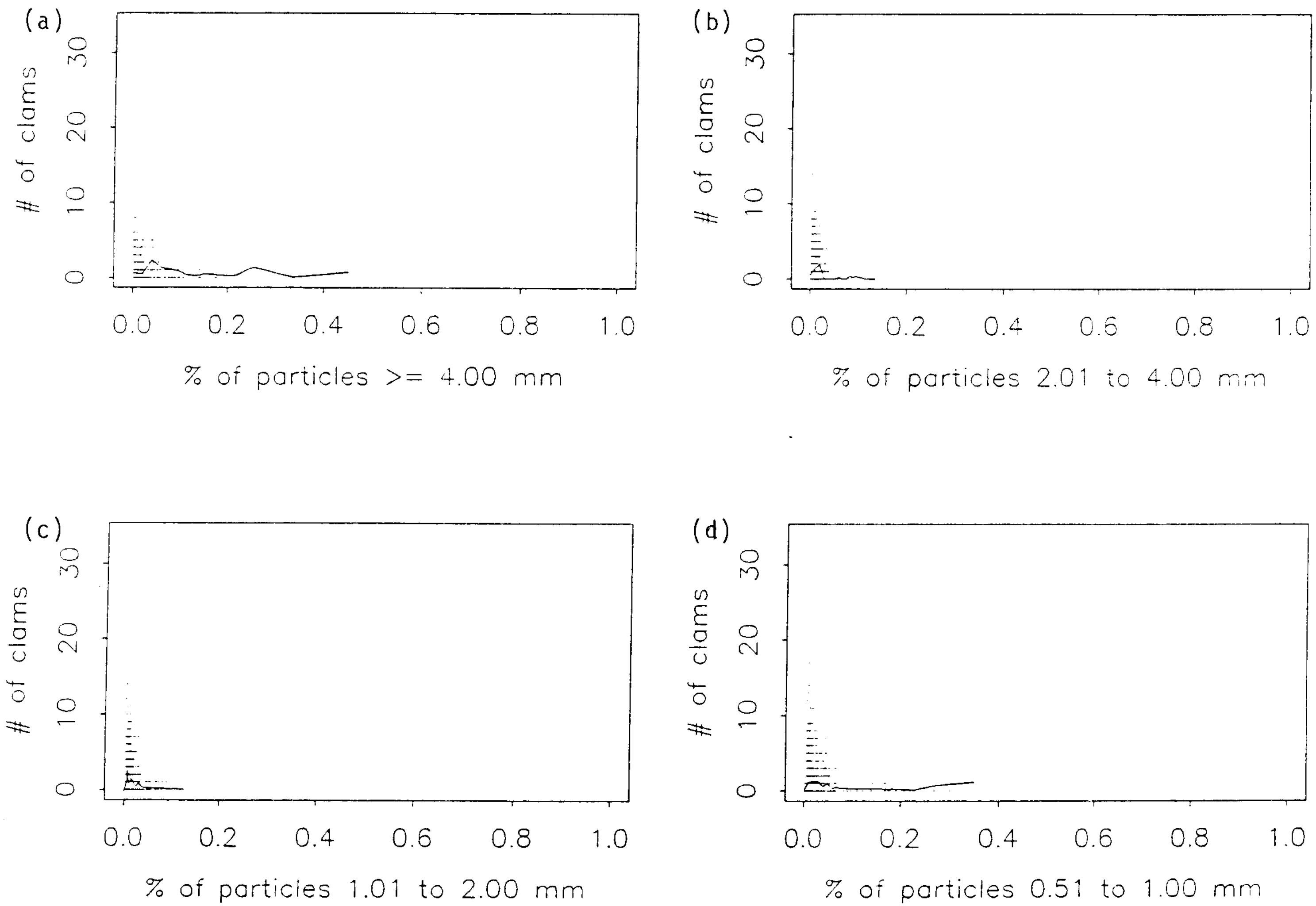




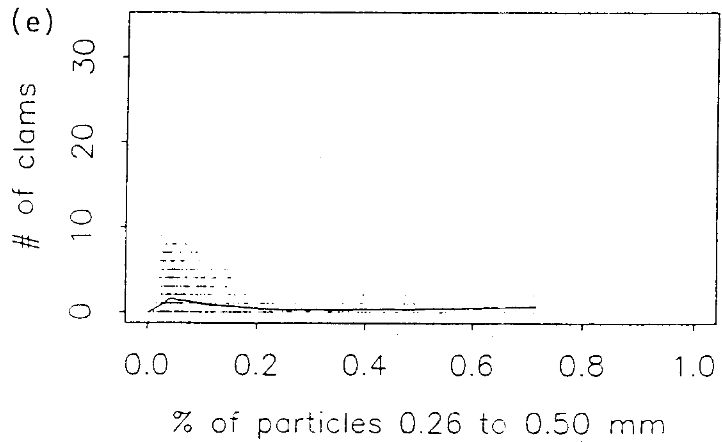
Figures 23a-h, continued.

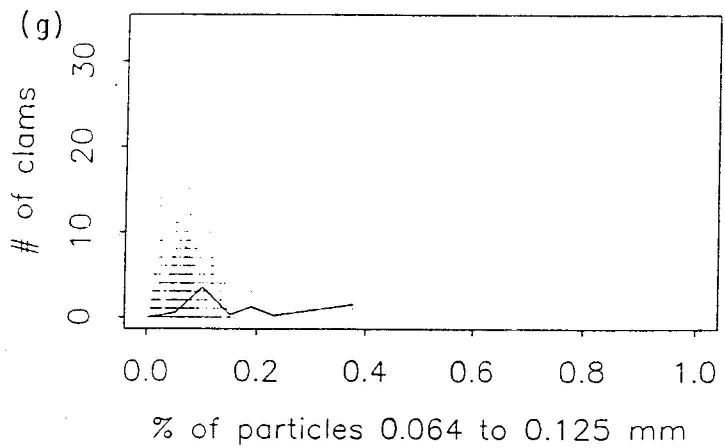

(f)
# of clams
0
5
10
15
0.0
0.2
0.4
0.6
0.8
1.0
% of particles 0.126 to 0.25 mm


(h)
# of clams
0
5
10
15
0.0
0.2
0.4
0.6
0.8
1.0
% of particles <= 0.063 mm

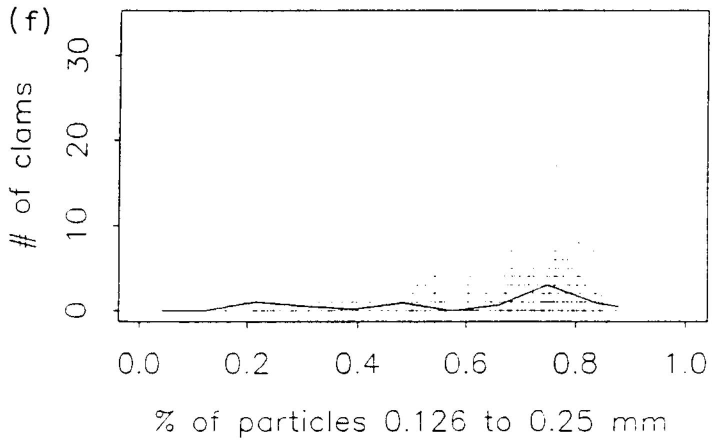


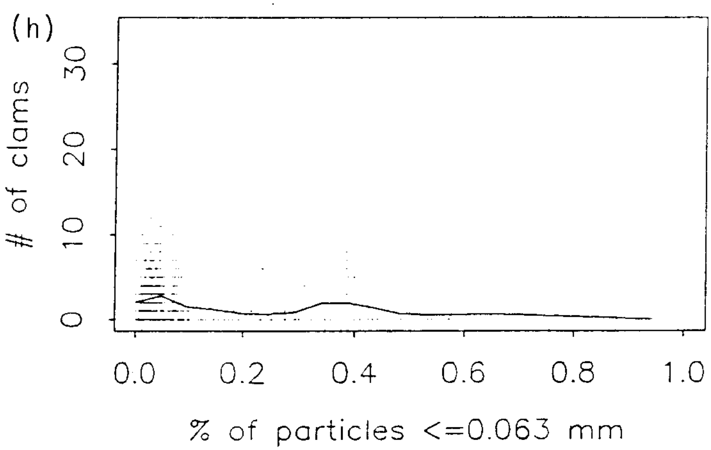
Figures 24a-h. Lowess analysis of grain size distribution in substrate cores, 1989.





Figures 24a-h, continued.


(f)
# of clams
0
10
20
30
0.0
0.2
0.4
0.6
0.8
1.0
% of particles 0.126 to 0.25 mm


(h)
# of clams
0
10
20
30
0.0
0.2
0.4
0.6
0.8
1.0
% of particles <=0.063 mm

sand (0.064 to 0.125 mm) (Figures 23g and 24g) and clam density increases when the smallest grain size category, silt and clay ($\leq$0.063 mm), comprises 15 percent (1988, Figure 23h) and 40 percent (1989, Figure 24h) of the substrate.

A stepwise regression of clam density against the percentages of each particle size category and the square of the percentages was performed to determine the amount variation in clam density explained by the category percentages. Quadratic terms were introduced because graphical analysis of the data suggested that quadratic relationships were possible. Distance from shore was also included to determine the amount of variation it explained in a model of factors thought to influence clam density.

Four variables are significant in the regression of the clam density and the grain size percentages corresponding to those densities in the 1988 data (Table 14). A positive linear relationship occurs between density and very fine sand and a quadratic relationship with grain sizes larger than very coarse sand (1.01 mm). Fine sand is the only significant substrate variable in the regression of the 1989 data (Table 15).

Because of the ambiguity in the results from the stepwise regression an alternative method was used to examine the relationship of clam density to grain size. The theoretical normal quantiles corresponding to the amount of substrate in each grain size category were regressed against the logarithm of the grain size categories to determine the mean and standard deviation of the grain size distribution in each core. Graphical methods were used to determine the grain size corresponding the highest density of clams over all samples in each year. The use of regression diagnostics was possible because the distribution of the grain sizes in each core was assumed to be normally distributed on a logarithmic scale (Krumbein 1936). A plot of the theoretical normal quantiles corresponding the particle sizes in a core against the natural logarithm of the grain size categories

Table 14. Stepwise multiple regression analysis of razor clam density function of substrate variables, 1988.

VARIABLES	coefficient	SE	P-value	Cumulative R^2
constant	-1.76	0.405	0.00	****
x1	20.26	5.302	0.00	0.204
x2	17.16	6.664	0.01	0.328
distance	0.05	0.001	0.00	0.372
x3	-329.6	69.2	0.00	0.397
x4	238.37	57.27	0.00	0.466

x1: % of core in size category 0.064 to 0.125 mm
x2: % larger than 4.00 mm^2
x3: % of core in size category 1.01 and 2.00 mm^2
x4: % of core in size category 2.01 and 4.00 mm^2

Table 15. Stepwise multiple regression analysis of razor clam density as a function of substrate variables, 1989.

VARIABLES	coefficient	SE	P-value	Cumulative R^2
constant	-1.528	0.244	0.00	****
distance	0.003	0.00	0.00	0.095
x1	3.379	0.372	0.00	0.15

x1: % of core in size category 0.126 and 0.25 mm resulted in a straight line if the assumption of normality was true. A regression of the quantiles and the transformed category variables yielded the mean grain size (intercept) and standard deviation (slope) of the grain sizes of the core sample (Coleman et al. 1980, p. 199). The contribution or weight of each particle size category in a core to the regression was determined with a robust regression (Chambers et al. 1983). If the components of any core did not contribute more than 75% in the regression that core was not considered to be lognormally distributed and was not used in subsequent analysis. The program could not determine normal quantiles for some cores.

Of the 31 cores examined in the analysis of the 1988 data; grain sizes in 5 cores did not fit a lognormal distribution adequately and were not included in the presentation of the data. Of 480 cores sampled in 1989, 381 were lognormally distributed and their mean grain size was used. Estimates are precise; coefficients of variation for the means in 1988 and 1989 are 0.09 and 0.08, respectively; the corresponding standard deviations are 0.24 and 0.20.

Mean grain size in a core is compared to the square root of mean clam density corresponding to that grain size for 1988 (Fig. 25) and 1989 (Fig. 26). A notched box plot (Chambers et al. 1983) of the distribution of the clams found associated with that grain size is located at each point. The largest numbers of clams were found in substrate with a mean grain size around 0.198 mm to 0.330 mm in the samples collected in 1988. Box plots reveal the skewed nature of the distribution of clams at each point resulting from the large number of samples with no clams. The box plot corresponding to mean grain size 0.198 mm is the least skewed indicating there are more clams where that grain size predominates. Samples from 1989 with a majority of grains 0.250 mm in width contained the most clams. The box plots in Figure 25 are skewed in the positive direction at the tails of the distribution and become more symmetrical towards the center indicating an increase in clams with mean grain sizes

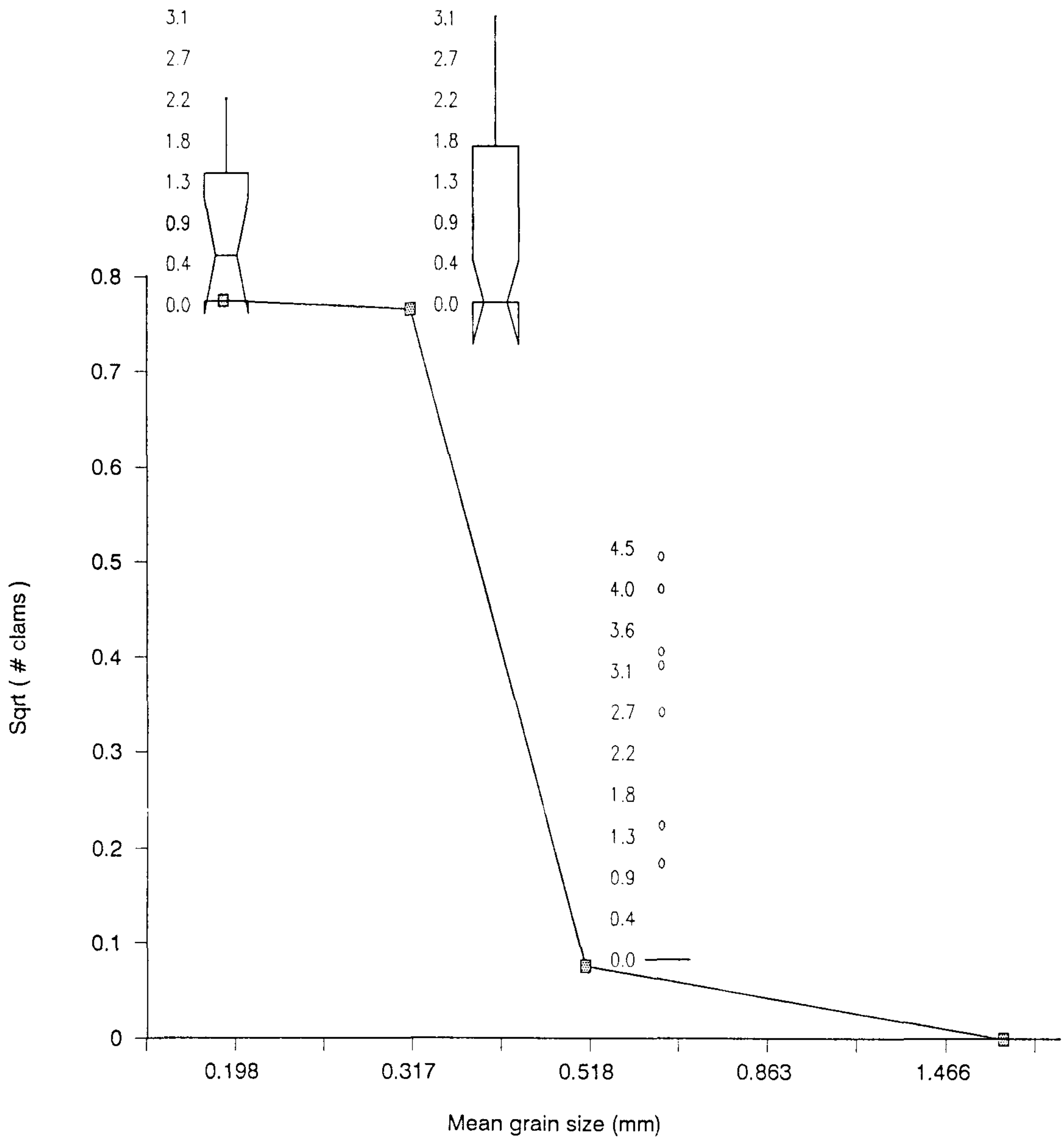


Figure 25. Mean number of clams found at average grain sizes with notched boxplots representing the distribution of clams, 1988.

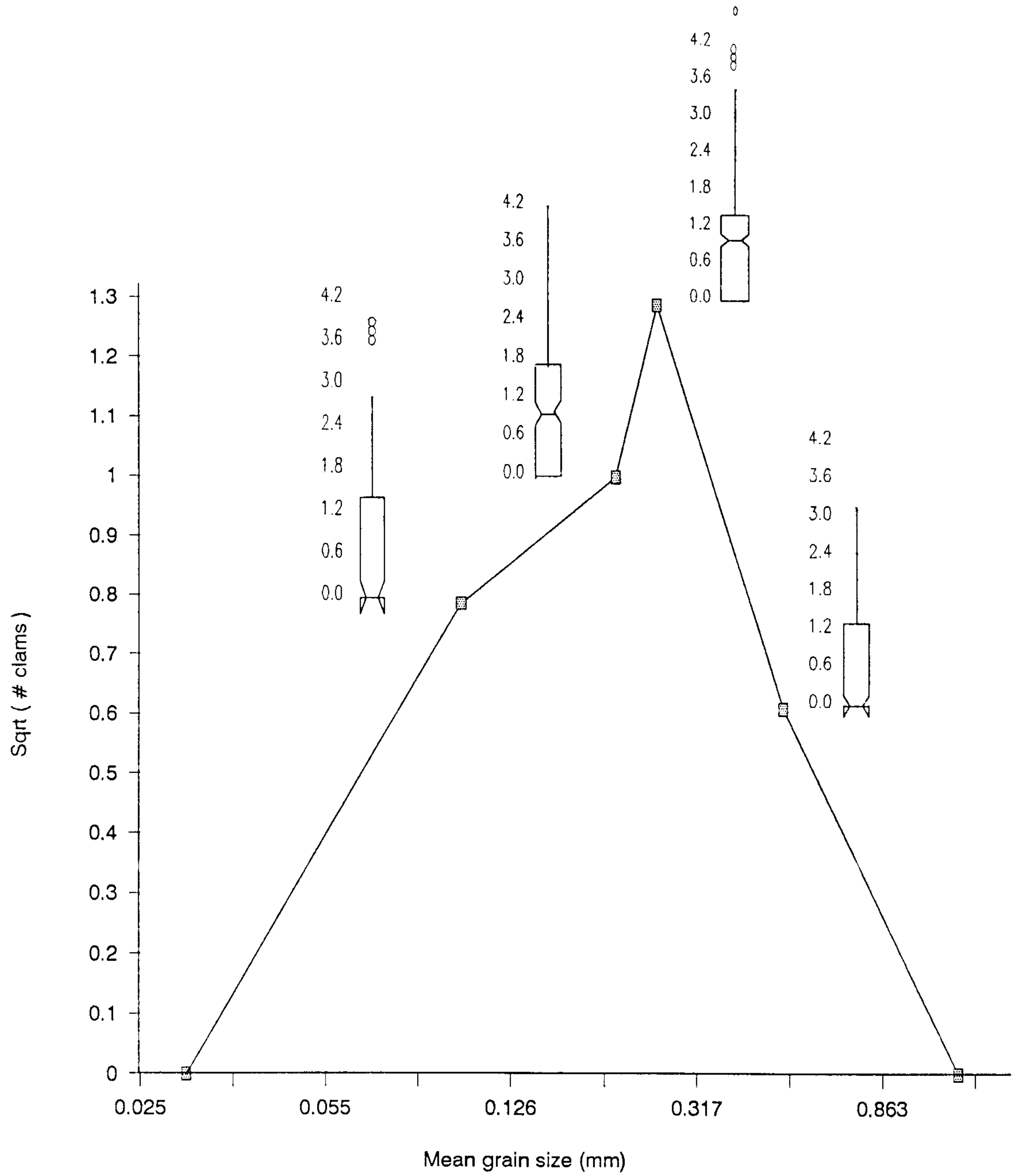


Figure 26. Mean number of clams found at average grain sizes with notched boxplots representing the distribution of clams, 1989.

0.126 mm to 0.317 mm.

Discussion

The null hypothesis that clam density does not depend on substrate cannot be rejected, although some potential relationships are evident. The general shapes of the Lowess curves between the two years agree. The most striking relationship occurs with fine sand (0.126 to 0.25 mm). Clam densities peak in both 1988 and 1989 when cores are 60 to 80 percent fine sand (Figures 23f and 24f). Stepwise regression analysis of the large 1989 data set chooses this as the only significant grain size category. The highest densities of clams were found where the average grain size was between 198 mm and 350 mm in 1988 (Figure 25) and at 250 mm in 1989 (Figure 26).

Low clam densities are found in the presence of most of the grain size categories. Peaks in Lowess curves of clam density versus the grain size categories occurred during both years when 30 percent of the core sample contained grains larger than pebbles (4.00 mm). The occurrence of higher numbers of clams in the largest grain size category demonstrated in Lowess curves is surprising because researchers (Nelson 1982, Nickerson 1975) have suggested that razor clams predominate in medium to fine grain sandy beaches. The increase in clam density with increasing percentage very fine sand (0.063 to 0.125 mm) agrees with the findings of these workers. Although knowledge of the biology of a species is never complete, it is reasonable to assume that the observations of previous researchers have some basis in fact and an increase in the presence of larger particles beyond some critical level would cause a decline in clam numbers; a negative coefficient on the square of the percent of very coarse sand (1.01 to 2.00 mm) (Table 14) supports this conclusion. However, the positive coefficients on the quadratic terms of the percentages of grain sizes larger than very coarse sand (2.01 mm) indicate the opposite; that clam numbers will increase quadratically with the percentage of those grain sizes found in the substrate.

The discrepancy between the substrate variables found to be significant in the 1988 data set compared with those from the analysis of the 1989 data as well as inconsistency of results from 1988 with the biology of the species are a possible consequence of two factors: 1) the small number of cores sampled in 1988 (n=31) and; 2) the overall lack of influence of substrate composition on clam density when compared to other factors such as distance from the gravel, exposure and exploitation rate. Distance is the only common variable between the two data sets in the results from the stepwise regression. In the stepwise regression of the data from 1989, distance explains the greatest amount of the variability in clam numbers.

Temperature and salinity

Water temperature is thought to trigger spawning. As noted in Chapter 1, the critical water temperature appears to be 8.3° C (Nickerson 1975 and Nelson 1982) on Alaskan beaches. The interplay of temperature and water currents can control distribution of razor clam larvae. Salinity is also an important influence on clam distribution.

Nelson (1982) writes:

> "In reduced quantities it (freshwater) retards growth and in large quantities it may result in death of individual clams. The influence of freshwater discharged by the Kasilof river reduces the maximum size attained by this species on Cohoe [*sic*] beach....At present there are no representatives of this species in close proximity to this river or adjacent to the Ninilchik river...."

McMullen (1967) attributed the absence of clams near Clam Gulch access to Clam Gulch creek, which alters its course across the beach regularly, rather than the heavy harvest that occurs there.

Methods

A YSI SCT33 was used to measure salinity and water temperature during the latter half of the 1988 field season and throughout the 1989 season. Measurements were usually taken at the beginning of the sampling day from 4 am to 11 am. Occasionally readings were made after sampling, between 10 am to 3 pm. Water samples were tested in the lab to check the accuracy of field measurements of salinity. Solutions of known salinity were prepared and measured with the YSI SCT33. A regression was performed of true salinity measurements versus meter values to determine a correction factor to be applied to field salinities.

Results

Temperature and corrected salinity values for 1988 and 1989 are presented in Tables 16 and 17. Water temperatures range from 12° C to 20° C during 1988 and 5° to 16° C in 1989. Colder temperatures were observed early in the season in 1989. The water was warmer after sampling when tides washed back in over the sun-warmed beaches. Salinity readings were variable. Lower salinities were found near the Kasilof and Ninilchik rivers and in the vicinity of Correa and Falls creeks in 1988. The lowest salinity measurement was taken in front of the town of Ninilchik in an area with high clam densities. In 1989 lower salinities were not always found near sources of freshwater. The lowest salinity (13.8 ppt) was encountered 1.3 miles from the nearest source of freshwater during a week of sunny weather. Salinities of 21.7 ppt were measured 0.8 kilometers north of Clam Gulch creek as well as next to Deep Creek.

Strong water currents have been observed in Cook Inlet and might explain the dispersion or concentration of freshwater along the Eastside beaches. Measurement error is a likely explanation for variable and extreme salinity readings; meter salinity readings differed from lab standards by as much as 12 part per thousand (ppt). Continual year-long monitoring of these variables is necessary for conclusions to be drawn about their influence on clam distribution and abundance. No relationship between clam density and water temperature or salinity could be inferred from the data.

Table 16. Water temperature and salinity values recorded on Eastside beaches before and after sampling, 1988.

Date	Temperature(°C)		Salinity (ppt)		Corrected salinity	
	before	after	before	after	before	after
07/29	12.5		20.0		39.9	
07/31		20.5		25.5		54.0
08/10	13.5		19.1		37.6	
08/12	13.8		15.9		29.4	
08/13	12.5	16.5	18.5	19.0	36.1	37.4
08/14	13.5	18.9	17.7	19.1	34.0	37.6
08/15	14.9		16.5	17.0	31.0	32.2
08/25	12.0		15.2		27.6	
08/26	12.0		17.5		33.5	
08/27	12.1		17.8		34.3	
08/28	12.0		15.9		29.4	
08/29		15.5	11.8		18.9	

Blanks are for days when no data was recorded.

Table 17. Water temperature and salinity values recorded on Eastside beaches before and after sampling, 1989.

Date	Temperature(°C)		Salinity(ppt)		Corrected salinity	
	before	after	before	after	before	after
05/03		5.7				
05/19	5.5		15.0		27.1	
05/20	5.0		17.0		32.2	
05/21	6.5		16.4		30.7	
05/22		6.5		16.5		31.0
05/23		13.0		16.5		31.0
05/24	10.0		18.0		34.8	
06/02	13.0		13.0		22.0	
06/04		10.5		15.1		27.4
06/07	9.5		16.0		29.7	
06/08	9.9		16.0		29.7	
06/19	11.0		14.4		25.6	
06/20		16.0		16.5		31.0
06/23	10.9		17.0		32.2	
07/02	11.2		17.0		32.2	
07/04	12.0		16.0		29.7	
07/06	12.0		16.5		31.0	
07/07	13.1		15.9		29.4	
07/17	11.5		15.5		28.4	
07/18	12.9		14.9		26.9	
07/19	14.0		15.4		28.1	
07/20	12.9		15.2		27.6	
07/21	13.6		15.6		28.7	
07/22	14.0		15.0		27.1	
07/23	13.1		15.0		27.1	
07/30	13.1		12.9		21.7	
07/31	12.6		14.4		25.6	
08/01	13.0		15.0		27.1	
08/02	12.5		14.0		24.6	
08/04	15.1					
08/15	12.8		14.2		25.1	
08/16	12.9					
08/17	15.0		12.9		21.7	
08/18	13.0		14.0		24.6	
08/19	12.5		15.5		28.4	
08/20	12.0		14.6		26.1	

Banks are for days when no data was recorded

Water current patterns

Investigation of the research conducted by other agencies on current patterns reveals that little information exists about near shore water circulation patterns in Cook Inlet. Figure 27 contains surface water circulation patterns for lower Cook Inlet (Burbank 1977). Northern and southern currents converge off the coast from the Ninilchik and Deep Creek drainages. Nearshore, south of the Ninilchik river, the clearer water from the south can be observed to replace the silt-laden waters from the north. South of Ninilchik variable densities of large clams occur (Nelson 1982). The relationship of water circulation patterns to clam density and distribution is unknown. No studies have investigated the stock composition of razor clams. Spawning of razor clams on Eastside beaches has never been observed; gonad fullness of sampled clams has been used as an indicator of the timing of spawning. None of the early developmental stages have ever been found. The difficulty in locating and tracing the movement of gametes, trocophore and veliger larvae and newly set clams makes stock identification by early life stages unlikely. Determining stock composition from juvenile and/or adult shell morphology would also be difficult because environmentally induced changes in shell structure could obscure patterns that might help identify separate stocks. The use of genetic characteristics to separate stocks may be feasible but has never been investigated.

Little of the oil from the spill that occurred in Upper Cook Inlet in 1987, or the spill in Prince William Sound, Alaska, in 1989, reached the Eastside beaches. The prevailing southerly currents stopped the spread of the oil into the Inlet. A few tarballs attributed to both spills were found at the high tide mark. Contamination of upper Cook Inlet nearshore, either north of Ninilchik or north of Anchor Point, is a greater threat to the Eastside razor clam populations than contamination of the central or southern Inlet or beyond.

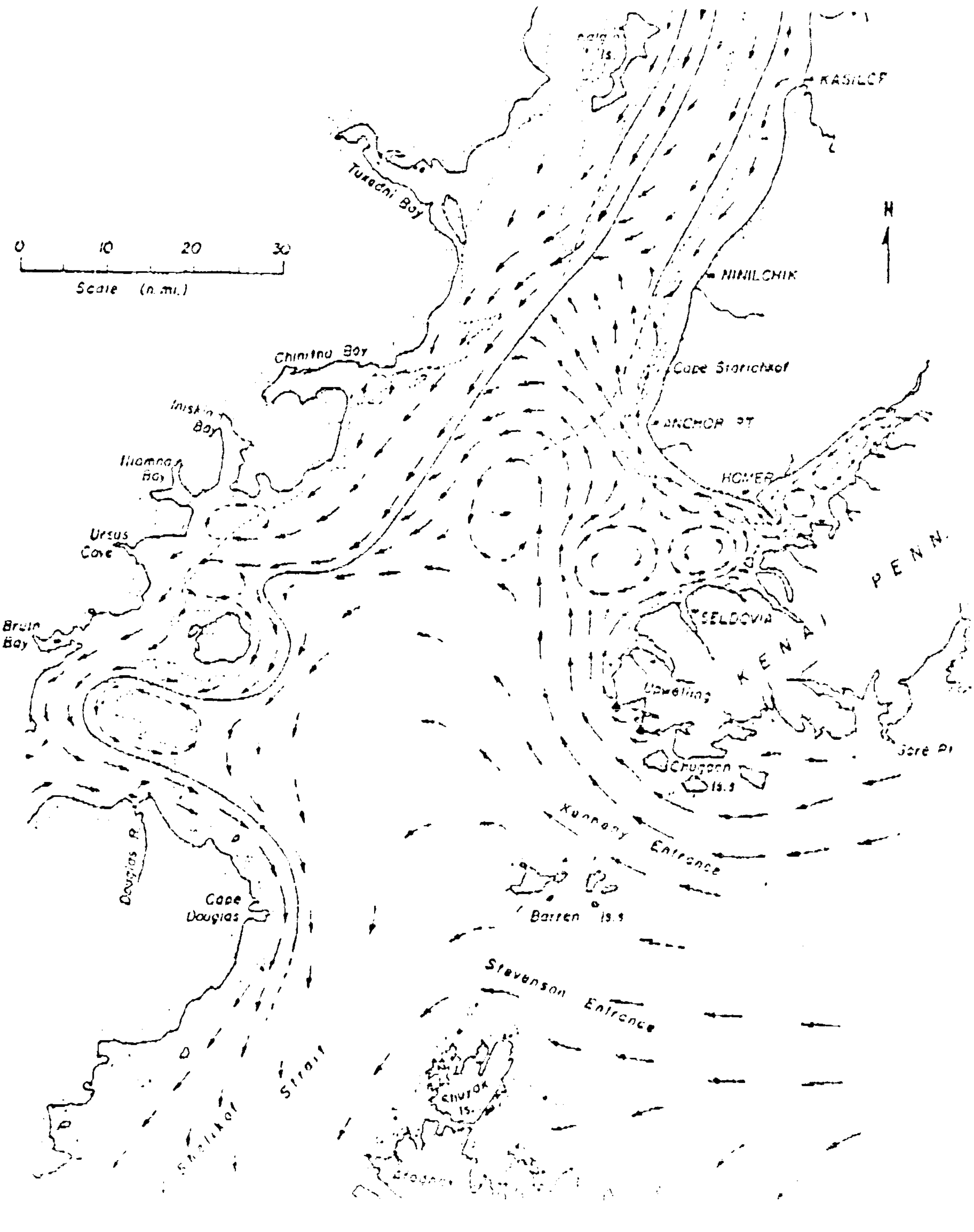


Figure 27. Surface current circulation patterns in upper Cook Inlet, Summer 1977 (Burbank 1977).

Canned razor clams

Cleaned razor clams (fresh or frozen) and juice
pint jars

Cut the clams into pieces of the desired size. Fill sterilized jars 2/3 full with clams and top them with juice to within one inch of the rim. Place lids on the jars and set them on the pressure cooker rack. Cover the bottom of the cooker with 1 inch of water. Seal the pressure cooker and bring to 10 lbs pressure. Start the timer and cook the clams for 90 minutes. Remove the jars and let them cool. Should the pressure drop to below 10 lbs before the 90 minutes has passed, restart the timer and cook at 10 lbs for another 90 minutes. When opening jars for use, first examine their tops to make sure they are sealed. The lid should be concave and make a hollow ringing sound when tapped. When the seal is broken, the jar should "inhale". Discard the contents of jars which do not pass these tests.

CHAPTER FIVE
SUSTAINED YIELD AND FUTURE RAZOR CLAM MANAGEMENT

The null hypothesis that razor clam density cannot be estimated on the eastside beaches of Cook Inlet is rejected for Clam Gulch. Precise density estimates were obtained in both 1988 and 1989 for all clams and in 1989 for harvestable clams. Other accomplishments of this study include: (1) generation of estimates of absolute abundance and other population parameters; (2) discovery that CPUE does not provide a sensitive estimate of abundance; (3) development of field sampling techniques; (4) discovery of a possible relationship between clam density and grain sizes between 0.126 mm and 0.400 mm.

The state constitution mandates that Alaskan resources be managed to maintain a sustained yield. A preliminary estimate of sustained yield for Clam Gulch can be made assuming a conservative exploitation rate obtained by fishing at rates less than natural mortality M (Gulland 1983). Exploitation rate $U = F(1-\exp(-Z))/Z$, where $Z=F+M$. Estimates of natural mortality probably range between 0.125 and 0.25 (Quinn and Jones 1989), resulting in a calculated conservative U of 11 to 20% when $F=M$. Thus a preliminary estimate of sustained yield for Clam Gulch is 0.3 to 0.6 million clams. Current harvests are lower than sustained yield. Surplus production at Clam Gulch estimated from CAGEAN is variable (Figure 28). Production is positive in each year under consideration indicating that over-harvest has not been a problem at Clam Gulch. (Surplus production for the year is estimated as the sum of catch and the change in abundance during the year and the present year) (Quinn et al. 1984).

Large numbers of harvesters continue to visit Eastside beaches, although the Statewide Harvest survey (Mills 1989) indicates effort dropped from 30,900 digger days in 1988 to 18,900 digger days in 1989. Effort at Ninilchik has increased since 1978. Since 1987 almost 50% of the total effort has occurred at Ninilchik. Few large clams and many

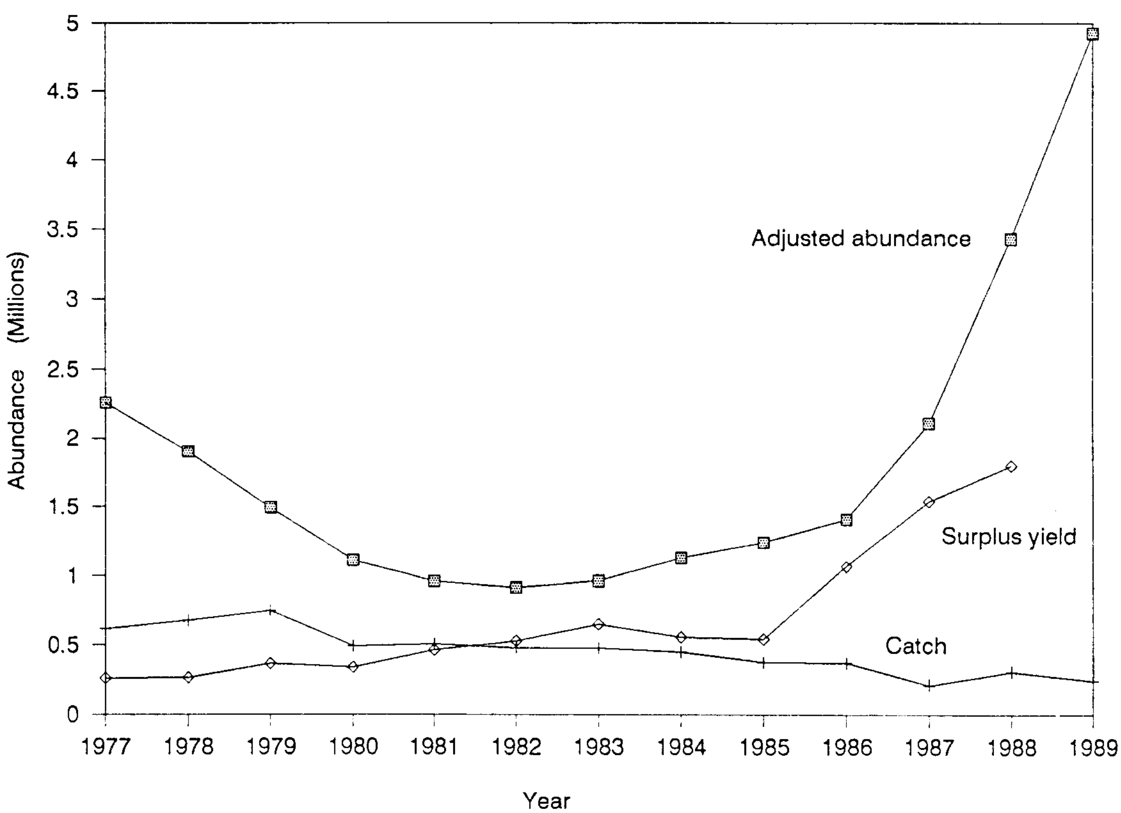


Figure 28. Surplus yield, adjusted abundance and estimated catch for Clam Gulch, 1977-1989.

small clams found in our samples indicate that the harvest at Ninilchik beach (not including the intertidal bar) may have surpassed the sustained yield. Unfortunately density estimates are too variable to allow precise estimation of this parameter. In 1990, sampling continued within 3.2 km of the access road at Clam Gulch and at Ninilchik. The location of transects at Ninilchik was refined in an attempt to include only suitable habitat for more precise density estimation. The Ninilchik bar, mentioned in Chapter 2, which receives most of the effort at Ninilchik, was included in sampling in 1990 but not 1989. Analysis of 1990 survey data is not complete but observation of many small clams and complaints of poor success by diggers at Ninilchik suggest that recruitment is occurring but that older stocks may be declining.

What direction should future sampling take to continue to provide reliable estimates of razor clam numbers at Clam Gulch and other Eastside beaches? Age-structured estimates of density and harvest are needed to predict abundance. Our sampling equipment has proven to be effective to obtain clams of all sizes. Clams less than 15 mm may be missed, suggesting population estimates including clams of this size may be biased. Consistent peaks in clams of certain sizes between Clam Gulch and the exploitation study area indicate that sampling of small areas can represent the length and (presumably) the age structure of larger stretches of beach.

A sampling plan similar to that of earlier studies conducted by the department could be adapted to the techniques developed here for future assessment and management of Eastside razor clam stocks. A two-stage random sampling plan would be applied to collect clams for age determination each year for use in age-structured analysis at Clam Gulch and the other beaches. The traditional management areas would be sampled with the modifications to the boundaries of the Clam Gulch and Ninilchik areas made in 1989. Sampling would be conducted at random locations so that 300 clam shells were collected from each beach during the field season. Ages determined from samples would ultimately be used to construct age-structured estimates of the population size for each beach. A survey to obtain density estimates to provide auxiliary information for age-structured analyses would rotate between the different beaches on different years. Shells could be collected during the creel census to provide estimates of the age structure of the harvest. Aerial surveys could be curtailed with modification of the Statewide Harvest Survey to include beach specific harvest estimates. Aerial survey estimates might be used for a few years for comparison with Statewide Harvest Survey estimates of relative effort if necessary.

Currently managers believe that effort will shift to more productive beaches before the sustained yield is exceeded on a particular beach (David Nelson, pers. comm.). A unique opportunity exists to test this belief at Ninilchik. Although the results of my research do not allow me to estimate the sustained yield at Ninilchik, I have witnessed increased levels of wastage of small clams which may eventually lead to recruitment over-fishing if spawning populations are depleted. I recommend that no steps be taken to restrict harvests at Ninilchik unless warranted by analysis of the 1990 data. Intensified sampling can be continued to monitor the population to obtain more precise density estimates, to determine exploitation and recovery rates, and collect shells for aging. Abundant populations at Clam Gulch and smaller populations on the other Eastside beaches can serve as "reserves" should the population at Ninilchik be jeopardized. At that point harvest can be distributed to these beaches if necessary to protect stocks at Ninilchik. In addition, to obtain more precise estimators of abundance at Ninilchik, areas encountered during sampling that are not deemed suitable as clam habitat should not be included in density calculations or in an estimate of the area of the beach. Unsuitable habitat can be identified prior to sampling.

I recommend continued sampling at Clam Gulch for the annual collection of the requisite number of shells to obtain information on age-structure and periodic surveys as needed to tune catch-age-analysis. Analysis of the 1990 data will determine if a survey is required in 1991. Between 5 and 15 transects should be sampled at Clam Gulch to obtain survey estimates; estimates with coefficients of variation of 15% were obtained by sampling 16 transects in 1988 and c.v.'s near 30% were obtained each tide period in 1989 by sampling between 3 and 4 transects. Intensified sampling at other Eastside beaches can be scheduled when satisfactory estimates of population parameters are obtained from the current beach under scrutiny. Further surveys should be conducted to modify the boundaries to minimize variability in density estimates.

Much remains to be understood about the razor clam population of the Eastside beaches. Validation of age composition is essential to improve estimates of population parameters from catch-age analysis. Presently, trends in effort and catch estimates and CAGEAN results appear to disagree: although effort declined (Table 8), clams aged 9+ disappeared from the catch at Clam Gulch from 1986 to 1989 (Table 10) while CAGEAN predicted that their abundance was increasing (Table 11). The combination of fishing mortality and abundance in explaining catch does not allow interpretation of trends in population size by observing changes in harvest. A knowledge of the trends in fishing mortality is necessary. CAGEAN allowed a better understanding of the dynamics of the razor clam population at Clam Gulch by analyis of age-structure coupled with survey sampling. I believe the variability in catch-at-age estimates (Table 10) may result partly from aging errors by individual readers and differing interpretation among readers, and also the small sample size of clams collected for aging. Lab studies of growth and factors influencing annuli formation coupled with in situ studies could provide answers to questions about razor clam age. A sample size of 300 is recommended for obtaining population estimates of sufficient precision and accuracy; less than 200 clams were obtained for aging during 1986 to 1989 (Table 9). As time progresses, larger sample sizes and more accurate age determination will improve the accuracy of recent abundance estimates.

Other questions about razor clam life history and population dynamics deserve attention. Pertinent avenues of investigation include: study of nearshore currents to explain the dynamics of larval dispersion and answer questions about the origin of stocks; data collection targeting small clams missed in our sampling to reveal factors affecting juvenile mortality and clam distribution patterns; measurement of gonadal indices and analysis of periodic plankton tows to determine spawn and set timing.

The razor clams on the Eastside beaches are a precious resource. Nowhere else are people allowed such a generous portion of the "finest food clam available on Pacific beaches" (Lassuy and Simons 1989). The bag limit on Eastside beaches is the first 60 razor clams dug each day throughout the year. In Washington state, disease and harvest pressures have reduced the limit to 15 clams and the season to every odd-numbered day during two months of the year (Dan Ayers, pers. comm.). Harvest statistics and the words of diggers, to department workers, in newspapers and letters, speak to the importance of this resource. In a world where growing numbers of animals are over-harvested, Alaskans can still think of the razor clam as a species in seemingly endless supply. But the low density of clams and the predominance of small clams in our samples indicate that Ninilchik may be over-harvested. The techniques used in this study allow managers to be able to determine the population size of razor clams on the Eastside Cook Inlet beaches for the first time. Investment of personnel and money to continue studies of razor clam population dynamics on Eastside beaches is necessary to provide the knowledge and information necessary for prudent management.

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APPENDIX A
Output from 3ST.for, 1988

Table 18. Distance (feet from gravel edge of beach) and elevation (tide height) codings used in sampling analyses.

Distance	Code	Elevation	Code
0- 50	1	4.50 +	1
51- 100	2	3.50 - 4.49	2
101- 150	3	2.50 - 3.49	3
151- 200	4	1.50 - 2.49	4
201- 250	5	0.50 - 1.49	5
251- 300	6	-0.49 - 0.49	6
301- 350	7	-1.49 - -0.50	7
351- 400	8	-2.49 - -1.50	8
401- 450	9	-3.49 - -2.50	9
451- 500	10	-4.49 - -3.50	10
501- 550	11		
551- 600	12		
601- 650	13		
651- 700	14		
701- 750	15		
751- 800	16		
801- 850	17		
851- 900	18		
901- 950	19		
951-1000	20		
1001-1050	21		
1051-1100	22		
1101-1150	23		
1151-1200	24		
1201-1250	25		
1251-1300	26		

Table 19a. Three-stage sampling estimates for Coho beach using all data and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
1	6	.000000	1	.000000
1	7	.000000	2	.000000
1	8	.000000	4	.000000
1	9	.000000	5	.000000
2	2	.000000	2	.000000
2	3	.000000	4	.000000
2	4	.000000	6	.000000
2	5	.000000	7	.000000
2	6	.000000	6	.000000
2	7	.000000	7	.000000
2	8	.000000	4	.000000
3	11	.000000	2	.000000
3	12	.000000	13	.000000
3	13	.000000	7	.000000
3	14	.200000	5	.200000
4	1	.000000	5	.000000
4	2	.000000	3	.000000
4	3	.000000	5	.000000
4	4	.000000	3	.000000
4	5	.000000	4	.000000
4	6	.400000	5	.244949
4	7	1.000000	6	.258199
5	1	.000000	7	.000000
5	2	.000000	8	.000000
5	3	.000000	6	.000000
5	4	.000000	4	.000000
5	5	.142857	7	.142857
5	6	.125000	8	.125000
5	7	1.500000	2	1.500000
5	8	.000000	1	.000000
5	9	1.000000	2	.000000
5	10	1.600000	5	.678233
5	11	1.400000	5	.678233
5	12	4.500000	6	1.147461
5	13	4.200000	5	1.019804
5	14	.000000	4	.000000
Total			176	

Table 19a, continued.

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
1	.000000	4	.000000
2	.000000	7	.000000
3	.050000	4	.050000
4	.200000	7	.144749
5	1.033418	14	.411007
Total		36	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.256684	5	.197613

Final estimates for three-stage sampling

$\bar{y}$	se_T	c.v.
.256684	.219283	.854291

Table 19b. Three-stage sampling estimates for Clam Gulch using all data and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
1	1	.000000	2	.000000
1	2	.000000	1	.000000
1	3	.000000	1	.000000
1	15	.000000	1	.000000
1	16	1.000000	1	.000000
1	18	.000000	1	.000000
1	19	3.500000	2	1.500000
1	20	5.000000	1	.000000
1	21	8.500000	2	1.500000
1	22	.750000	4	.750000
1	23	.000000	3	.000000
2	4	.000000	1	.000000
2	6	.000000	1	.000000
2	7	.000000	1	.000000
2	10	.000000	2	.000000
2	11	1.000000	1	.000000
2	12	.000000	1	.000000
2	13	.500000	2	.500000
2	14	1.000000	1	.000000
2	17	6.000000	3	2.000000
2	18	6.000000	1	.000000
2	19	7.000000	2	.000000
2	20	3.000000	1	.000000
2	21	4.000000	2	1.000000
2	22	4.000000	2	.000000
2	23	7.000000	1	.000000
2	24	2.000000	3	.577350
2	25	4.000000	7	.487950
2	26	3.666667	3	1.763834
3	2	.000000	1	.000000
3	3	.000000	1	.000000
3	4	.000000	1	.000000
3	5	.000000	1	.000000
3	6	.500000	2	.500000
3	7	2.000000	2	2.000000
3	8	.333333	3	.333333
3	9	6.000000	4	1.080123
3	10	2.500000	2	1.500000
3	11	2.500000	2	1.500000
3	12	4.666667	3	.881917
3	13	5.000000	1	.000000
3	14	2.250000	4	1.652019
3	15	3.000000	5	.948683
3	16	5.000000	11	.603023

Table 19b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
4	1	.000000	1	.000000
4	2	.000000	1	.000000
4	5	.000000	1	.000000
4	7	4.000000	1	.000000
4	9	3.000000	1	.000000
4	11	3.000000	1	.000000
4	12	7.000000	1	.000000
4	13	2.000000	1	.000000
4	14	2.000000	1	.000000
4	15	3.000000	1	.000000
4	18	1.000000	1	.000000
4	19	2.000000	1	.000000
5	2	.000000	1	.000000
5	4	1.000000	2	.000000
5	5	1.500000	2	.500000
5	6	1.000000	1	.000000
5	8	.000000	1	.000000
5	9	1.500000	2	.500000
5	10	2.000000	2	2.000000
5	11	5.000000	2	1.000000
5	12	3.333333	3	2.333333
5	13	.750000	4	.478714
5	14	2.000000	2	2.000000
5	15	2.000000	4	.577350
5	16	.000000	3	.000000
5	17	1.666667	3	1.666667
5	18	.000000	3	.000000
5	19	.000000	4	.000000
5	20	.000000	4	.000000
5	21	.000000	2	.000000
6	1	.000000	3	.000000
6	2	.000000	2	.000000
6	3	.000000	4	.000000
6	4	.250000	4	.250000
6	5	.000000	2	.000000
6	6	.333333	3	.333333
6	7	.000000	3	.000000
6	8	.666667	3	.666667
6	9	.000000	5	.000000
6	10	.000000	3	.000000
6	11	.500000	6	.341565
6	12	.000000	4	.000000
7	1	.000000	5	.000000
7	2	.000000	5	.000000
7	3	.000000	6	.000000
7	4	.000000	7	.000000

Table 19b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	s.e.$_{ij}$
7	5	.000000	7	.000000
7	6	.000000	3	.000000
7	7	.000000	5	.000000
8	2	.000000	1	.000000
8	3	.000000	2	.000000
8	4	.000000	1	.000000
8	5	.000000	1	.000000
8	6	.500000	2	.500000
8	8	7.000000	1	.000000
8	9	9.000000	1	.000000
8	10	4.500000	2	1.500000
8	11	1.000000	1	.000000
8	12	11.000000	1	.000000
8	13	6.000000	2	.000000
8	14	4.500000	4	.645497
8	15	3.500000	6	.921954
9	1	.000000	4	.000000
9	2	.222222	9	.146986
9	3	.285714	7	.184428
9	4	.400000	10	.163299
10	1	.000000	1	.000000
10	2	.000000	7	.000000
10	3	.444444	9	.242161
10	4	.285714	7	.184428
10	5	.666667	6	.333333
10	6	.300000	10	.152753
10	7	2.166667	6	.945751
11	1	.000000	5	.000000
11	2	.000000	5	.000000
11	3	.500000	4	.500000
11	4	1.666667	3	.333333
11	5	3.200000	10	.573488
11	6	3.222222	9	.795435
12	1	.000000	3	.000000
12	3	1.500000	2	.500000
12	4	.800000	5	.374166
12	5	3.142857	7	.459221
12	6	1.833333	6	.307318
13	1	.000000	7	.000000
13	2	.000000	7	.000000
13	3	.000000	7	.000000
13	4	.000000	7	.000000
14	1	3.500000	2	3.500000
14	2	.000000	4	.000000
14	3	.142857	7	.142857
14	4	.555556	9	.337931
14	5	.200000	5	.200000

Table 19b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
15	2	.000000	1	.000000
15	3	.000000	5	.000000
15	4	.250000	4	.250000
16	2	.000000	3	.000000
16	3	.000000	2	.000000
16	4	.000000	1	.000000
16	5	.000000	3	.000000
16	6	.000000	2	.000000
16	8	.000000	1	.000000
16	9	.500000	2	.500000
Total			473	

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
1	1.704545	11	.848004
2	2.731481	18	.606060
3	2.250000	15	.546695
4	2.250000	12	.578988
5	1.208333	18	.321710
6	.145833	12	.068138
7	.000000	7	.000000
8	3.615385	13	1.047209
9	.226984	4	.084127
10	.551927	7	.283502
11	1.431481	6	.615241
12	1.455238	5	.526311
13	.000000	4	.000000
14	.879683	5	.661432
15	.083333	3	.083333
16	.071429	7	.071429
Total		147	

First-stage sampling estimator

$\bar{y}$	n	s.e.
1.162853	16	.279263

Final estimates for three-stage sampling

$\bar{\bar{y}}$	$s.e._T$	c.v.
1.162853	.311895	.268215

Table 19c. Three-stage sampling estimates for Ninilchik using all data and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
1	1	.000000	2	.000000
1	2	.000000	2	.000000
1	3	.000000	5	.000000
1	4	.000000	7	.000000
1	5	.000000	6	.000000
1	7	.000000	4	.000000
1	8	.000000	7	.000000
2	1	.000000	7	.000000
2	2	.000000	6	.000000
2	3	.000000	4	.000000
2	4	.000000	4	.000000
2	5	.000000	7	.000000
2	6	.142857	7	.142857
2	7	.000000	7	.000000
3	1	.000000	1	.000000
3	2	.000000	6	.000000
3	3	.000000	6	.000000
4	1	.000000	1	.000000
4	5	.166667	6	.166667
4	6	.111111	9	.111111
4	7	.363636	11	.152120
4	8	.000000	9	.000000
5	1	.000000	2	.000000
5	2	.000000	6	.000000
5	3	.000000	4	.000000
5	4	.076923	13	.076923
5	5	.000000	3	.000000
6	1	.000000	1	.000000
6	2	.000000	3	.000000
6	3	.133333	15	.090851
6	4	.000000	1	.000000
7	1	.000000	1	.000000
7	2	.000000	1	.000000
7	4	.000000	1	.000000
7	5	.250000	4	.250000
7	6	.500000	6	.341565
7	7	.000000	2	.000000
7	8	.000000	2	.000000
7	9	.250000	4	.250000
7	10	2.000000	1	.000000
7	11	1.500000	2	.500000
7	12	4.500000	2	2.500000
7	14	1.250000	4	.250000
7	15	1.125000	8	.398098

Table 19c, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
7	16	1.000000	11	.426401
7	17	.500000	10	.401386
8	4	.000000	2	.000000
8	5	.000000	1	.000000
8	6	.000000	1	.000000
8	7	.000000	3	.000000
8	8	.000000	2	.000000
8	9	1.333333	3	.881917
8	10	.000000	3	.000000
8	11	.000000	3	.000000
8	12	.000000	3	.000000
8	13	.000000	1	.000000
8	14	.000000	1	.000000
8	15	.500000	2	.500000
8	16	.000000	2	.000000
8	17	1.000000	2	.000000
8	18	.000000	2	.000000
9	2	1.000000	1	.000000
9	3	4.000000	2	3.000000
9	4	8.500000	2	1.500000
9	5	12.000000	1	.000000
9	6	20.000000	2	5.000000
9	7	7.000000	1	.000000
9	8	12.166667	6	1.815060
10	3	.166667	6	.166667
10	4	.000000	7	.000000
10	5	.000000	4	.000000
10	6	.000000	8	.000000
Total			302	

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
1	.000000	7	.000000
2	.020408	7	.020408
3	.000000	3	.000000
4	.128283	5	.067109
5	.015385	5	.015385
6	.033333	4	.033333
7	.858333	15	.307850
8	.188889	15	.108947
9	9.238095	7	2.354737
10	.041667	4	.041667
Total		72	

First-stage sampling estimator

$\bar{y}$	n	s.e.
1.052439	10	.913227

Table 19c, continued.

Final estimates for three-stage sampling

$\bar{y}$	s.e.$_T$	c.v.
1.052439	.948194	.900949

Table 20a. Three-stage sampling estimates for Coho beach using only transects where elevations were measured and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
2	2	.000000	2	.000000
2	3	.000000	4	.000000
2	4	.000000	6	.000000
2	5	.000000	7	.000000
2	6	.000000	6	.000000
2	7	.000000	7	.000000
2	8	.000000	4	.000000
3	11	.000000	2	.000000
3	12	.000000	13	.000000
3	13	.000000	7	.000000
3	14	.200000	5	.200000
4	1	.000000	5	.000000
4	2	.000000	3	.000000
4	3	.000000	5	.000000
4	4	.000000	3	.000000
4	5	.000000	4	.000000
4	6	.400000	5	.244949
4	7	1.000000	6	.258199
5	1	.000000	7	.000000
5	2	.000000	8	.000000
5	3	.000000	6	.000000
5	4	.000000	4	.000000
5	5	.142857	7	.142857
5	6	.125000	8	.125000
5	7	1.500000	2	1.500000
5	8	.000000	1	.000000
5	9	1.000000	2	.000000
5	10	1.600000	5	.678233
5	11	1.400000	5	.678233
5	12	4.500000	6	1.147461
5	13	4.200000	5	1.019804
5	14	.000000	4	.000000
Total			164	

Table 20a, continued.

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
2	.000000	7	.000000
3	.050000	4	.050000
4	.200000	7	.144749
5	1.033418	14	.411007
Total		32	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.320855	4	.241292

Final estimates for three-stage sampling

$\bar{y}$	$s.e._T$	c.v.
.320855	.268956	.838248

Table 20b. Three-stage sampling estimates for Clam Gulch using only transects where elevations were measured and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
1	1	.000000	2	.000000
1	2	.000000	1	.000000
1	3	.000000	1	.000000
1	15	.000000	1	.000000
1	16	1.000000	1	.000000
1	18	.000000	1	.000000
1	19	3.500000	2	1.500000
1	20	5.000000	1	.000000
1	21	8.500000	2	1.500000
1	22	.750000	4	.750000
1	23	.000000	3	.000000
2	4	.000000	1	.000000
2	6	.000000	1	.000000
2	7	.000000	1	.000000
2	10	.000000	2	.000000
2	11	1.000000	1	.000000
2	12	.000000	1	.000000
2	13	.500000	2	.500000
2	14	1.000000	1	.000000
2	17	6.000000	3	2.000000
2	18	6.000000	1	.000000
2	19	7.000000	2	.000000
2	20	3.000000	1	.000000
2	21	4.000000	2	1.000000
2	22	4.000000	2	.000000
2	23	7.000000	1	.000000
2	24	2.000000	3	.577350
2	25	4.000000	7	.487950
2	26	3.666667	3	1.763834
3	2	.000000	1	.000000
3	3	.000000	1	.000000
3	4	.000000	1	.000000
3	5	.000000	1	.000000
3	6	.500000	2	.500000
3	7	2.000000	2	2.000000
3	8	.333333	3	.333333
3	9	6.000000	4	1.080123
3	10	2.500000	2	1.500000
3	11	2.500000	2	1.500000
3	12	4.666667	3	.881917
3	13	5.000000	1	.000000
3	14	2.250000	4	1.652019
3	15	3.000000	5	.948683

Table 20b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
3	16	5.000000	11	.603023
5	2	.000000	1	.000000
5	4	1.000000	2	.000000
5	5	1.500000	2	.500000
5	6	1.000000	1	.000000
5	8	.000000	1	.000000
5	9	1.500000	2	.500000
5	10	2.000000	2	2.000000
5	11	5.000000	2	1.000000
5	12	3.333333	3	2.333333
5	13	.750000	4	.478714
5	14	2.000000	2	2.000000
5	15	2.000000	4	.577350
5	16	.000000	3	.000000
5	17	1.666667	3	1.666667
5	18	.000000	3	.000000
5	19	.000000	4	.000000
5	20	.000000	4	.000000
5	21	.000000	2	.000000
6	1	.000000	3	.000000
6	2	.000000	2	.000000
6	3	.000000	4	.000000
6	4	.250000	4	.250000
6	5	.000000	2	.000000
6	6	.333333	3	.333333
6	7	.000000	3	.000000
6	8	.666667	3	.666667
6	9	.000000	5	.000000
6	10	.000000	3	.000000
6	11	.500000	6	.341565
6	12	.000000	4	.000000
7	1	.000000	5	.000000
7	2	.000000	5	.000000
7	3	.000000	6	.000000
7	4	.000000	7	.000000
7	5	.000000	7	.000000
7	6	.000000	3	.000000
7	7	.000000	5	.000000
8	2	.000000	1	.000000
8	3	.000000	2	.000000
8	4	.000000	1	.000000
8	5	.000000	1	.000000
8	6	.500000	2	.500000
8	8	7.000000	1	.000000
8	9	9.000000	1	.000000
8	10	4.500000	2	1.500000
8	11	1.000000	1	.000000

Table 20b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	s.e.$_{ij}$
8	12	11.000000	1	.000000
8	13	6.000000	2	.000000
8	14	4.500000	4	.645497
8	15	3.500000	6	.921954
9	1	.000000	4	.000000
9	2	.222222	9	.146986
9	3	.285714	7	.184428
9	4	.400000	10	.163299
10	1	.000000	1	.000000
10	2	.000000	7	.000000
10	3	.444444	9	.242161
10	4	.285714	7	.184428
10	5	.666667	6	.333333
10	6	.300000	10	.152753
10	7	2.166667	6	.945751
11	1	.000000	5	.000000
11	2	.000000	5	.000000
11	3	.500000	4	.500000
11	4	1.666667	3	.333333
11	5	3.200000	10	.573488
11	6	3.222222	9	.795435
12	1	.000000	3	.000000
12	3	1.500000	2	.500000
12	4	.800000	5	.374166
12	5	3.142857	7	.459221
12	6	1.833333	6	.307318
13	1	.000000	7	.000000
13	2	.000000	7	.000000
13	3	.000000	7	.000000
13	4	.000000	7	.000000
14	1	3.500000	2	3.500000
14	2	.000000	4	.000000
14	3	.142857	7	.142857
14	4	.555556	9	.337931
14	5	.200000	5	.200000
Total			437	

Second-stage sampling estimators

i	$\bar{y}_{i}$	n_{i}	s.e.$_{i}$
1	1.704545	11	.848004
2	2.731481	18	.606060
3	2.250000	15	.546695
5	1.208333	18	.321710
6	.145833	12	.068138
7	.000000	7	.000000
8	3.615385	13	1.047209
9	.226984	4	.084127

Table 20b, continued.

i	$\bar{y}_i$	n_i	$s.e._i$
10	.551927	7	.283502
11	1.431481	6	.615241
12	1.455238	5	.526311
13	.000000	4	.000000
14	.879683	5	.661432
Total		125	

First-stage sampling estimator

$\bar{y}$	n	$s.e.$
1.246222	13	.310998

Final estimates for three-stage sampling

$\bar{y}$	$s.e._T$	c.v.
1.246222	.351873	.282352

Table 20c. Three-stage sampling estimates for Ninilchik using only transects where elevations were measured and distance as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
1	1	.000000	2	.000000
1	2	.000000	2	.000000
1	3	.000000	5	.000000
1	4	.000000	7	.000000
1	5	.000000	6	.000000
1	7	.000000	4	.000000
1	8	.000000	7	.000000
2	1	.000000	7	.000000
2	2	.000000	6	.000000
2	3	.000000	4	.000000
2	4	.000000	4	.000000
2	5	.000000	7	.000000
2	6	.142857	7	.142857
2	7	.000000	7	.000000
3	1	.000000	1	.000000
3	2	.000000	6	.000000
3	3	.000000	6	.000000
4	1	.000000	1	.000000
4	5	.166667	6	.166667
4	6	.111111	9	.111111
4	7	.363636	11	.152120
4	8	.000000	9	.000000
5	1	.000000	2	.000000
5	2	.000000	6	.000000
5	3	.000000	4	.000000
5	4	.076923	13	.076923
5	5	.000000	3	.000000
6	1	.000000	1	.000000
6	2	.000000	3	.000000
6	3	.133333	15	.090851
6	4	.000000	1	.000000
7	1	.000000	1	.000000
7	2	.000000	1	.000000
7	4	.000000	1	.000000
7	5	.250000	4	.250000
7	6	.500000	6	.341565
7	7	.000000	2	.000000
7	8	.000000	2	.000000
7	9	.250000	4	.250000
7	10	2.000000	1	.000000
7	11	1.500000	2	.500000
7	12	4.500000	2	2.500000
7	14	1.250000	4	.250000

Table 20c, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
7	15	1.125000	8	.398098
7	16	1.000000	11	.426401
7	17	.500000	10	.401386
8	4	.000000	2	.000000
8	5	.000000	1	.000000
8	6	.000000	1	.000000
8	7	.000000	3	.000000
8	8	.000000	2	.000000
8	9	1.333333	3	.881917
8	10	.000000	3	.000000
8	11	.000000	3	.000000
8	12	.000000	3	.000000
8	13	.000000	1	.000000
8	14	.000000	1	.000000
8	15	.500000	2	.500000
8	16	.000000	2	.000000
8	17	1.000000	2	.000000
8	18	.000000	2	.000000
10	3	.166667	6	.166667
10	4	.000000	7	.000000
10	5	.000000	4	.000000
10	6	.000000	8	.000000
Total			287	

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
1	.000000	7	.000000
2	.020408	7	.020408
3	.000000	3	.000000
4	.128283	5	.067109
5	.015385	5	.015385
6	.033333	4	.033333
7	.858333	15	.307850
8	.188889	15	.108947
10	.041667	4	.041667
Total		65	

First-stage sampling estimator

$\bar{y}$	n	$s.e.$
.142922	9	.091934

Final estimates for three-stage sampling

$\bar{y}$	$s.e._T$	c.v.
.142922	.101939	.713249

Table 21a. Three-stage sampling estimates for Coho beach using only transects where elevations were measured and elevation as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
2	1	.000000	2	.000000
2	2	.000000	4	.000000
2	4	.000000	6	.000000
2	5	.000000	7	.000000
2	7	.000000	6	.000000
2	8	.000000	7	.000000
2	9	.000000	4	.000000
3	1	.000000	8	.000000
3	2	.000000	6	.000000
3	3	.000000	2	.000000
3	4	.000000	6	.000000
3	6	.200000	5	.200000
4	2	.000000	5	.000000
4	3	.000000	3	.000000
4	4	.000000	5	.000000
4	5	.000000	3	.000000
4	6	.000000	4	.000000
4	7	.727273	11	.194978
5	1	.000000	25	.000000
5	2	.142857	7	.142857
5	3	.142857	7	.142857
5	5	.000000	1	.000000
5	6	1.000000	3	1.000000
5	7	1.000000	2	.000000
5	8	1.600000	5	.678233
5	9	1.400000	5	.678233
5	10	3.200000	15	.744504
Total			164	

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
2	.000000	7	.000000
3	.040000	5	.040000
4	.121212	6	.121212
5	.942857	9	.349603
Total		27	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.276017	4	.223705

Table 21a, continued.

Final estimates for three-stage sampling

$\bar{y}$	$s.e._T$	c.v.
.276017	.246593	.893396

Table 21b. Three-stage sampling estimates for Clam Gulch using only transects where elevations were measured and elevation as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	s.e.$_{ij}$
1	5	.000000	1	.000000
1	8	.000000	3	.000000
1	10	2.200000	15	.817662
2	2	.142857	7	.142857
2	3	.666667	3	.333333
2	4	6.000000	3	2.000000
2	5	6.666667	3	.333333
2	6	3.800000	5	.374166
2	7	3.200000	5	1.019804
2	8	4.166667	6	.542627
2	9	3.666667	3	1.763834
3	3	.000000	3	.000000
3	4	2.500000	12	.874729
3	5	3.625000	8	.652947
3	6	3.950000	20	.559488
5	10	1.177778	45	.275771
6	2	.000000	3	.000000
6	3	.000000	2	.000000
6	4	.000000	4	.000000
6	5	.166667	6	.166667
6	6	.260870	23	.129111
6	7	.000000	4	.000000
7	1	.000000	5	.000000
7	2	.000000	5	.000000
7	3	.000000	6	.000000
7	4	.000000	7	.000000
7	5	.000000	7	.000000
7	6	.000000	8	.000000
8	9	3.560000	25	.630026
9	3	.000000	4	.000000
9	5	.222222	9	.146986
9	6	.352941	17	.119471
10	3	.000000	5	.000000
10	4	.000000	3	.000000
10	5	.461538	13	.183114
10	6	.400000	5	.400000
10	7	.900000	20	.339504
11	5	.000000	4	.000000
11	6	.000000	6	.000000
11	7	1.000000	7	.377964
11	8	3.200000	10	.573488
11	9	3.222222	9	.795435
12	6	1.705882	17	.381220

Table 21b, continued.

i	j	$\bar{y}_{ij}$	n_{ij}	$s.e._{ij}$
12	7	1.833333	6	.307318
13	1	.000000	7	.000000
13	4	.000000	7	.000000
13	6	.000000	14	.000000
14	2	.000000	1	.000000
14	3	.000000	4	.000000
14	5	.142857	7	.142857
14	6	.200000	5	.200000
14	7	1.714286	7	.968904
14	8	.000000	3	.000000
Total			437	

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	$s.e._i$
1	.733333	3	.733333
2	3.538690	8	.804188
3	2.518750	4	.895206
5	1.177778	1	.000000
6	.071256	6	.046678
7	.000000	6	.000000
8	3.560000	1	.000000
9	.191721	3	.103020
10	.352308	5	.167692
11	1.484444	5	.728177
12	1.769608	2	.063725
13	.000000	3	.000000
14	.342857	6	.276519
Total		53	

First-stage sampling estimator

$\bar{y}$	n	s.e.
1.210827	13	.358274

Final estimates for three-stage sampling

$\bar{\bar{y}}$	$s.e._T$	c.v.
1.210827	.386604	.319289

Table 21c. Three-stage sampling estimates for Ninilchik using only transects where elevations were measured and elevation as the second-stage index.

Third-stage sampling estimators

i	j	$\bar{y}_{ij}$	n_{ij}	s.e.$_{ij}$
1	5	.000000	4	.000000
1	6	.000000	12	.000000
1	7	.000000	10	.000000
1	10	.000000	7	.000000
2	7	.000000	28	.000000
2	8	.071429	14	.071429
3	6	.000000	1	.000000
3	7	.000000	12	.000000
4	7	.000000	4	.000000
4	8	.166667	12	.112367
4	9	.200000	20	.091766
5	10	.035714	28	.035714
6	7	.000000	1	.000000
6	8	.105263	19	.072335
7	1	.000000	1	.000000
7	2	.000000	2	.000000
7	3	.400000	10	.221108
7	4	.000000	2	.000000
7	5	.250000	4	.250000
7	6	1.000000	5	.447214
7	7	3.000000	4	1.354006
7	8	1.100000	10	.314466
7	9	.750000	16	.309570
7	10	.800000	5	.800000
8	6	.000000	4	.000000
8	7	.363636	11	.278722
8	8	.000000	8	.000000
8	9	.375000	8	.182981
10	3	.166667	6	.166667
10	4	.000000	7	.000000
10	5	.000000	4	.000000
10	6	.000000	7	.000000
10	7	.000000	1	.000000
Total			287	

Table 21c, continued.

Second-stage sampling estimators

i	$\bar{y}_i$	n_i	s.e.$_i$
1	.000000	4	.000000
2	.035714	2	.035714
3	.000000	2	.000000
4	.122222	3	.061864
5	.035714	1	.000000
6	.052632	2	.052632
7	.730000	10	.284917
8	.184659	4	.106638
10	.033333	5	.033333
Total		33	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.132697	9	.077270

Final estimates for three-stage sampling

$\bar{y}$	s.e.$_T$	c.v.
.132697	.088137	.664194

APPENDIX B
Output from 2ST.for, 1988

Table 22a. Two-stage sampling estimates for Coho beach using all data and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	12	.000000
2	.000000	13	.000000
3	.000000	15	.000000
4	.000000	13	.000000
5	.055556	18	.055556
6	.150000	20	.081918
7	.529412	17	.212091
8	.000000	9	.000000
9	.285714	7	.184428
10	1.600000	5	.678233
11	1.000000	7	.534522
12	1.421053	19	.598809
13	1.750000	12	.739830
14	.111111	9	.111111
Total		176	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.493060	14	.176009

Final estimates for two-stage sampling

$\bar{y}$	s.e.$_T$	c.v.
.493060	.199805	.405234

Table 22b. Two-stage sampling estimates for Clam Gulch using all data and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.212121	33	.212121
2	.041667	48	.029148
3	.210526	57	.069625
4	.387097	62	.084038
5	1.377778	45	.262638
6	1.205128	39	.275347
7	1.166667	18	.451938
8	1.111111	9	.771802
9	2.666667	15	.837608
10	1.636364	11	.664321
11	1.769231	13	.532939
12	3.230769	13	1.044852
13	2.300000	10	.775314
14	2.833333	12	.694495
15	2.764706	17	.473794
16	3.733333	15	.713587
17	3.833333	6	1.514742
18	1.166667	6	.980363
19	2.555556	9	1.001542
20	1.333333	6	.881917
21	4.166667	6	1.621042
22	1.833333	6	.833333
23	1.750000	4	1.750000
24	2.000000	3	.577350
25	4.000000	7	.487950
26	3.666667	3	1.763834
Total		473	

First-stage sampling estimator

$\bar{\bar{y}}$	n	s.e.
2.036617	26	.242403

Final estimates for two-stage sampling

$\bar{\bar{y}}$	s.e.$_T$	c.v.
2.036617	.298327	.146481

Table 22c. Two-stage sampling estimates for Ninilchik using all data and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	15	.000000
2	.040000	25	.040000
3	.261905	42	.170602
4	.486486	37	.325635
5	.437500	32	.375504
6	1.363636	33	.868011
7	.392857	28	.253751
8	2.807692	26	1.096876
9	.714286	7	.420560
10	.500000	4	.500000
11	.600000	5	.400000
12	1.800000	5	1.356466
13	.000000	1	.000000
14	1.000000	5	.316228
15	1.000000	10	.333333
16	.846154	13	.372898
17	.583333	12	.336162
18	.000000	2	.000000
Total		302	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.712992	18	.168240

Final estimates for two-stage sampling

$\bar{y}$	s.e.$_T$	c.v.
.712992	.210522	.295266

Table 23a. Two-stage sampling estimates for Coho beach using only transects where elevations were measured and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	12	.000000
2	.000000	13	.000000
3	.000000	15	.000000
4	.000000	13	.000000
5	.055556	18	.055556
6	.157895	19	.085947
7	.600000	15	.235028
8	.000000	5	.000000
9	1.000000	2	.000000
10	1.600000	5	.678233
11	1.000000	7	.534522
12	1.421053	19	.598809
13	1.750000	12	.739830
14	.111111	9	.111111
Total		164	

First-stage sampling estimator

y	n	s.e.
.549687	14	.178702

Final estimates for two-stage sampling

$\bar{y}$	$s.e._T$	c.v.
.549687	.201890	.367281

Table 23b. Two-stage sampling estimates for Clam Gulch using only transects where elevations were measured and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.218750	32	.218750
2	.046512	43	.032495
3	.240000	50	.078558
4	.403509	57	.089763
5	1.512195	41	.279638
6	1.270270	37	.286452
7	1.000000	17	.445566
8	1.250000	8	.860855
9	3.000000	12	1.015038
10	1.636364	11	.664321
11	1.666667	12	.568535
12	2.916667	12	1.083333
13	2.333333	9	.866025
14	2.909091	11	.756241
15	2.750000	16	.504149
16	3.733333	15	.713587
17	3.833333	6	1.514742
18	1.200000	5	1.200000
19	2.625000	8	1.132909
20	1.333333	6	.881917
21	4.166667	6	1.621042
22	1.833333	6	.833333
23	1.750000	4	1.750000
24	2.000000	3	.577350
25	4.000000	7	.487950
26	3.666667	3	1.763834
Total		437	

First-stage sampling estimator

$\bar{y}$	n	s.e.
2.049809	26	.241440

Final estimates for two-stage sampling

$\bar{y}$	$s.e._T$	c.v.
2.049809	.301588	.147130

Table 23c. Two-stage sampling estimates for Ninilchik using only transects where elevations were measured and distance as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	15	.000000
2	.000000	24	.000000
3	.075000	40	.042176
4	.028571	35	.028571
5	.064516	31	.044853
6	.161290	31	.081607
7	.148148	27	.069670
8	.000000	20	.000000
9	.714286	7	.420560
10	.500000	4	.500000
11	.600000	5	.400000
12	1.800000	5	1.356466
13	.000000	1	.000000
14	1.000000	5	.316228
15	1.000000	10	.333333
16	.846154	13	.372898
17	.583333	12	.336162
18	.000000	2	.000000
Total		287	

First-stage sampling estimator

$\bar{y}$	n	s.e.
.417850	18	.118986

Final estimates for two-stage sampling

$\bar{y}$	s.e.$_T$	c.v.
.417850	.152077	.363950

Table 24a. Two-stage sampling estimates for Coho beach using only transects where elevations were measured and elevation as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	35	.000000
2	.045455	22	.045455
3	.083333	12	.083333
4	.000000	17	.000000
5	.000000	11	.000000
6	.333333	12	.256235
7	.526316	19	.140351
8	.666667	12	.355335
9	.777778	9	.433903
10	3.200000	15	.744504
Total		164	

First-stage sampling estimator

$\bar{\bar{y}}$	n	s.e.
.563288	10	.307563

Final estimates for two-stage sampling

$\bar{\bar{y}}$	s.e.$_T$	c.v.
.563288	.322842	.573139

Table 24b. Two-stage sampling estimates for Clam Gulch using only transects where elevations were measured and elevation as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	12	.000000
2	.062500	16	.062500
3	.074074	27	.051361
4	1.333333	36	.440058
5	1.017241	58	.255006
6	1.183333	120	.177116
7	1.306122	49	.247786
8	2.590909	22	.458961
9	3.486486	37	.477137
10	1.433333	60	.292434
Total		437	

First-stage sampling estimator

$\bar{y}$	n	s.e.
1.248733	10	.353674

Final estimates for two-stage sampling

$\bar{y}$	$s.e._T$	c.v.
1.248733	.365928	.293040

Table 24c. Two-stage sampling estimates for Ninilchik using only transects where elevations were measured and elevation as the second-stage index.

Second-stage sampling estimators

i	$\bar{y}_i$	n	s.e.
1	.000000	1	.000000
2	.000000	2	.000000
3	.312500	16	.150520
4	.000000	9	.000000
5	.083333	12	.083333
6	.172414	29	.100110
7	.225352	71	.113827
8	.253968	63	.074941
9	.431818	44	.127580
10	.125000	40	.102454
Total		287	

First-stage sampling estimator

$\bar{\bar{y}}$	n	s.e.
.160439	10	.046464

Final estimates for two-stage sampling

$\bar{\bar{y}}$	s.e.$_T$	c.v.
.160439	.054850	.341877